STUDIES

FROM THE

Yale Psychological Laboratory

EDITED BY

EDWARD W. SCRIPTURE, Ph.D.

Instructor in Experimental Psychology

1892-1893

Issued on October 1st, 1893

YALE UNIVERSITY,

NEW HAVEN, CONN.

1893

PRESS OF TUTTLE, MOREHOUSE & TAYLOR, NEW HAVEN, CONN.

CONTENTS.

PREFATORY NOTE.

The monographs contained in the following pages are the results of such investigations as reached a successful conclusion during the first year of the existence of the laboratory. The first of them is essentially a thesis accepted by the university for the degree of Ph.D.

In the computation of results it was not deemed advisable during the first year of our work to depart from the usual psychological method of taking the average deviation (or mean variation) as the mean of the absolute differences of the observed values from the arithmetical average of the observations. MV means the same as in most other psychological publications, i. e.

$$MV = \frac{v_1 + v_2 + \ldots + v_n}{n}$$

where $v_1, v_2, \ldots, v_n$ are the differences of the single observations from their average, taken without regard to sign, and n is the number of observations. We propose, however, in the future to follow with such modifications as necessary the methods of the science of measurement as developed by Gauss. The sign $^\sigma$ means thousandths of a second.

INVESTIGATIONS IN REACTION-TIME AND ATTENTION

BY

CHARLES B. BLISS, PH.D.

INTRODUCTION.

The work described in the following pages occupied the greater part of my time during the academical year 1892–93. As I was the first to carry on such experiments in the Yale psychological laboratory, a large part of my fall term was spent in preparing the apparatus and in developing a method which should serve for all future experiments. The result is a method for measuring reaction-time which is in some parts entirely new. In operation it is simple and accurate, having been built up step by step as the needs required. In the hope that the whole or parts of it will be of value to other laboratories, the description has been made as complete as seemed necessary.

In the experimental part of the work I am especially indebted to the following persons for valuable time which they have spent in the reaction-room. To Messrs. Thomas J. Lloyd, William I. Cranford and Joshua A. Gilbert of the Graduate Department, and to Mr. Joseph Roby, a member of the senior class in Yale College.

During the second term, Abraham Fisher, the laboratory steward, recorded all the experiments, thus leaving me free to do my own reacting. The advantage of doing my own introspective observing was an important one.

Dr. Scripture not only suggested the first problem but has always been ready to assist me in carrying out the experiments and in arranging the apparatus. In fact, parts of the apparatus were invented by him. One line of research was carried out at the suggestion of Professor Ladd, who has always shown a kindly interest in my work.

In the drawing of the diagrams valuable suggestions were received from Mr. Walter I. Lowe, a member of the Graduate Department.

APPARATUS.

Apparatus for measuring reaction-time must furnish some means for giving the reactor a stimulus and for measuring the interval of time between the moment in which the stimulus is given, and that in which the reaction takes place. The time-measurement must be accurate to thousandths of a second and the person experimented upon must, so far as possible, be free from all influences which would distract his attention.

This last requirement was met by placing the reactor in a separate room, so constructed as to be free from light and sound. In the center of the building a room was finished off, twelve feet long, nine feet wide and nine feet high. Inside of this room a smaller one was constructed with a door and ventilator corresponding to those of the outer room. This inner room was supported on thick cushions of felt and rubber, the only connection with the outer room being heavy canvas around the doors and the ventilators for the purpose of holding back the sawdust with which the space between the two walls was filled. The door was likewise made double with beveled edges, like a safe door, so that it shut tightly against the canvas connecting the two rooms. A thick mat, made of hair felt and covered with cloth, was hung up over the door on the inside. This acted like a heavy curtain to check any sounds which might creep in around the door.

During the experiments the door of the dark room was not shut more than five or ten minutes at a time. For that period the ventilator could be kept closed without producing any bad effects. In the case of longer experiments it is proposed to open a ventilator in the floor and pass a current of air through the room by means of a blower. The ventilators can then be packed with wool or some other material, which will allow the passage of air, but effectually shut out all sound. The experiments described in this paper were all taken in the winter, and the temperature of the room was the same as that of the rest of the building. Very loud sounds in adjacent rooms can still be heard in the reaction-room. Heavy wagons, which occasionally pass along the street, jar the whole building and with it this room; the shaking can be felt but not heard. When the adjacent rooms are kept quiet, the reaction-room is free from sound. The reactor is thus practically removed from all external disturbances in sight or hearing.

There are two methods in use for measuring intervals of time to thousandths of a second, the graphic method and that of the chrono-

scope. The Hipp chronoscope is the most perfect piece of mechanism thus far constructed for recording such short intervals of time on a dial. An immense amount of time and labor has been spent in perfecting this chronoscope and in investigating its accuracy. In its most perfect form there is always a very large error in the results as they are read off from the dial. This error depends on the relative strength of the electric current passing through it and that of a spring which pulls back the armature when the circuit is broken. A control-apparatus must be used which consists of a hammer so arranged that it can be made to fall certain distances. The time required for this fall is carefully measured by the graphic method and the spring of the chronoscope adjusted until the chronoscope itself measures the time of fall with the same result. Other times are accurately obtained by correcting the recorded results. The chronoscope in one of its forms is then accurate only for times of about that length. G. E. Müller claimed[1] that Münsterberg's experiments contain a large error even though he had corrected his chronoscope by a control-hammer. That particular hammer was made to correct the chronoscope for intervals of 160 thousandths of a second, whereas many of Münsterberg's experiments gave times as high as half a second. Although Münsterberg seems to have avoided the error supposed, yet the danger is evident. A more elaborate control-hammer has been constructed by Wundt.[2] By means of this hammer correct times can be given up to 616 thousandths of a second. The mean variation of this hammer in 200 experiments was 1.04 thousandths of a second. The mean variation of chronoscope and hammer combined was also 1.04^{σ}. This, the best result which has yet been obtained from the chronoscope, is ten times as great as the mean variation of the graphic method in its simple form.[3]

In the graphic method a tuning-fork, kept in constant vibration by a current of electricity, is allowed to trace a curve on a revolving drum covered with smoked paper. This gives a representation of a period of time divided according to the rapidity with which the fork vibrates. Using a fork which vibrates one hundred times a second the drum is revolved with such rapidity that the single waves are so long that we make no error in estimating tenths of a vibration and so reading the results in thousandths of a second.

[1] Göttingische gelehrte Anzeigen, 1891, p. 398.

[2] Külpe and Kirschmann, *Ein neuer Apparat zum Controle zeitmessender Instrumente*, Phil. Stud. 1892 VII 145.

[3] Wundt, Physiol. Psych. 3 ed. II 282.

Now, given this tuning-fork curve, all that is needed is some method of registering alongside of it the exact instants at which the stimulus and the reaction occur. Fig. 1 shows the usual way in

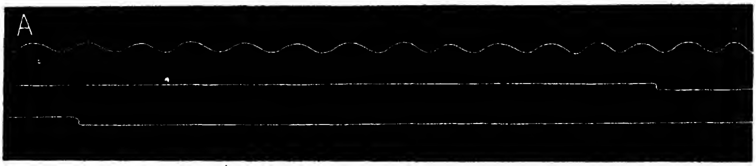


Fig. 1.

which this is done. The upper curve is drawn by the recording point of a tuning-fork which vibrates one hundred times a second. The other two lines are drawn by electro-magnetic time-markers. The current passing through one passes also through the key whose closing produces the stimulus. The current through the other passes through a key in the reaction-room. The movement of each key is thus recorded by a break in the straight line drawn by its time-marker. These points are then transferred to the tuning-fork curve by dropping perpendiculars from the points to the curve. The measure of the time which has elapsed between the movement of the two keys can then be counted off on the time-curve.

The objection to the use of this method in making a large number of experiments is that it takes a long time to drop the perpendiculars and that great variable errors are likely at the two points. These errors are increased by the fact that the time-markers must be adjusted so that they shall both touch the drum in the same perpendicular line. Moreover, the latent times of the markers may not be the same.

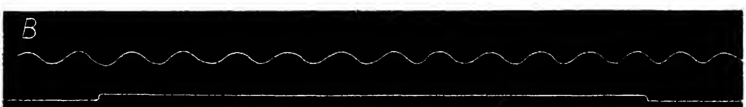


Fig. 2.

An improvement upon this method has been made by doing away with one of the markers. The same current is passed through both keys and through one time-marker. Fig. 2 shows a measurement made by this method. Closing the stimulus-key draws the lever of the marker toward its magnet, making a break in the straight line. Opening the key in the reaction-room breaks the circuit and allows the lever to fly back again, thus making a second break in the same straight line. These two points are transferred to the time-curve and the interval is counted off as before. The result is that the

number of lines on the smoked paper is reduced by one-third, allowing more experiments to be taken on the same paper and making the records easier to count. But more important than this is the fact that one large source of error is removed. The accuracy of the result no longer depends on the adjustment of the two markers so that they shall touch the drum in the same horizontal line.

The latent time for the two movements is generally different. And there still remains an error and a great loss of time in transferring the two points to the time-curve. What is wanted is some means of registering the interval directly upon the curve itself. This has been accomplished after trial of various methods. The first suggestion was to arrange an apparatus so that the stimulus-key when it was closed should start the curve and the reaction-key stop it by being opened. This was done by taking the fork from the drum and replacing it by one of the electro-magnetic markers. The current was run through the tuning-fork, the time-marker and the reaction-key, but it was short-circuited through the stimulus-key.

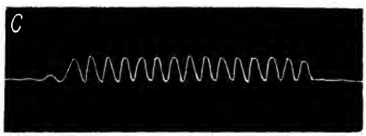


Fig. 3.

As long as the stimulus-key remained untouched, the marker did not vibrate; but as soon as it was touched, the record began. When the reaction-key was pressed, the entire circuit was broken and the record ceased. Such a record is shown in fig. 3.

At first sight this might appear to solve the problem but a closer examination shows that this is not the case.

Fig. 4 shows the way in which the Pfeil marker works. B is the battery, F the tuning-fork, M an electro-magnet, S a steel armature which serves as a spring; the lever is attached at O. This lever swings on a pivot at H; when the circuit is complete the vibration of the fork alternately makes and breaks the current at X. As soon as it is made the coil in the fork becomes a magnet, pulls the prongs inward and breaks the circuit. This demagnetizes the coil, the prongs fly back and the process is repeated indefinitely. But when the current is closed at X, the magnet M draws down the armature and its lever. When the current is broken in the fork the armature flies back carrying the lever with it. Thus the point P vibrates in unison with the fork.

Let CDE be a section of the curve which would be traced by the marker. From C to D the motion of the point comes from the spring that causes the armature to fly back. From D to E the motive force is a combination of the spring and the magnet. Now if the stimulus-key, which starts the current through the marker, is opened between C and D, no effect will be produced until the point D is reached for no current is passing through the circuit. Therefore the chances are one in two that the beginning of the movement will be too late by anywhere from 0 to 5^σ, the section of the curve from C to E being 10^σ with a tuning-fork which vibrates 100 times a second.

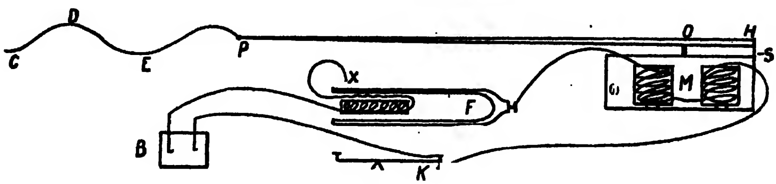


Fig. 4.

At the end of the interval the case is not quite so clear. If the reaction-key breaks the circuit between C and D, there will be no effect until the point D is reached. But, unlike the beginning, the effect will not be shown at D. For, when the marker is in motion the motive force, between D and E is a combination of the spring and the magnet. Near D the spring is stretched. The tension gradually decreases passing from a positive to a negative quantity somewhere below the middle point, while the force of the magnet gradually increases the nearer the armature approaches it. Therefore the effect of a break in the current is not shown until the magnetic component of the motive force reaches a certain strength in proportion to that of the spring before it is interrupted. Suppose that this takes place when three-fifths of the distance DE have been passed over, then the chances are seven to ten that the end of the interval will be registered anywhere from 0 to 7^σ too late.

In a large number of experiments these errors at the beginning and end would partially balance each other, but their presence would still be shown by the large mean variation. The beginnings would on the average be 1.25^σ too late and the ends too late by 2.45^σ. In a small number of experiments the results are not accurate beyond hundredths of a second. By using a fork which vibrates 500 times a second, the error would be reduced to 2^σ and by using a fork vibrating 2000 times a second, the method would be accurate to

thousandths of a second. This however is impossible since the time-markers are not delicate enough to record such rapid vibrations. Even if they were, the task of counting so many wave-lengths would render the method of no practical use.

The next step was to arrange the apparatus so that the time-marker vibrated continually in unison with the tuning-fork, but yet

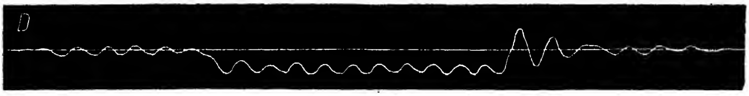


Fig. 5.

so that closing the stimulus-key sent an additional current through the time-marker, which additional current was released by opening the key in the reaction-room. The result is shown in fig. 5. During the interval to be measured the vibration of the marker continues in a different line from that of the normal time-curve. Here we have the beginning and end of the interval accurately marked. By adjusting the strength of the two currents and the rapidity of the drum, this method will probably be quite successful. If so, it will be superior to any other method heretofore used. It is possible however only with the Pfeil marker which has a steel spring as shown in fig. 4; for it consists in a partial magnetization of the electro-magnet which draws the spring part way but still leaves room for it to be affected by the current passing through the tuning-fork.

This method was not used in the following experiments for the reason that a much better plan suggested itself. Instead of trying to change the curve to mark the beginning and end of the interval the apparatus was so arranged that closing the stimulus-key broke the primary current of a spark-coil and sent a spark from the tuning-fork to the metal drum through the smoked paper. Opening the key in the reaction-room likewise broke the same current and sent another spark through the smoked paper. Fig. 6 gives a speci-

Fig. 6.

men record taken by this method. Here we have both ends of the interval marked exactly, there is no time lost and no error arising from transferring the interval to the time-curve or in adjusting the markers on the drum.

the drum. Opening the stimulus-key starts the marker vibrating and an instant later gives the stimulus which is marked by a spark on the curve. As soon as the spark from the reaction-key has been recorded, the multiple-key is released, and the marker ceases to vibrate before the drum has made a complete revolution. The marker is then moved to the right or the left by a turn of the screw and another record is taken. A similar record on an ordinary drum is shown in fig. 10.

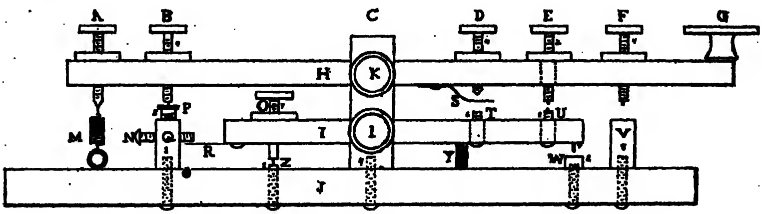
Fig. 10.

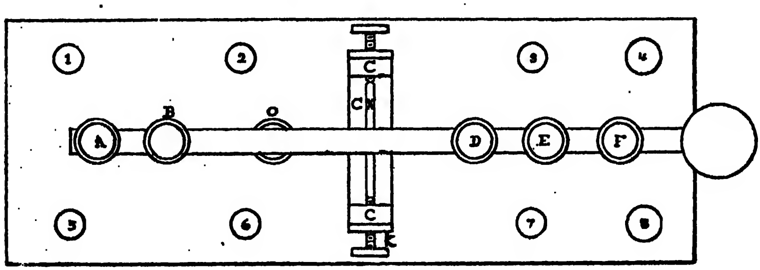
The other drum is constructed, as can be seen in fig. 13, so that every turn of the crank moves the drum itself half an inch to the right or left. In this case the standard holding the marker or the tuning-fork remains stationary. One hand turns the drum once around while the other closes the stimulus-key. The reaction always follows before the revolution is completed. For simple reaction-time this is much the better drum of the two. The records are always the same distance apart and can be made to begin in the same horizontal line on the drum, thus making the counting of the records much easier than those of the electrical drum which are scattered over the paper and are liable to be cut in two when that is removed from the drum. For other purposes the electrical drum is to be preferred.

It is evident from the various functions ascribed to the stimulus-key that something more than the ordinary telegraph-key is implied. In every case it is assumed that it produces the stimulus and records it at the same instant on the drum by means of a spark. In addition to this it sometimes starts the tuning-fork curve just before the stimulus and stops it just after the reaction has taken place. The necessity for some contrivance by which such things might be done was felt at the beginning of the work and led to the invention, by Dr. Scripture, of the multiple-key.

Figs. 11 and 12 show drawings of this key. It consists of two square bars of brass I and H rotating on small steel axles X held in place by check-screws K L passing through the upright parts C of a firm brass frame which is screwed to the wooden base J. One end of each bar is held by a spring M, Y; the strength of M is regulated by the screw A. Besides this there are four other screws B, D, E, F, which pass through the upper lever, one of them F

being insulated from the lever by hard rubber. The screw B rests upon a small steel plate P, insulated by a hard rubber screw from the brass stanchion Q and connected by wire on the underside of the base with binding-post 5. None of the binding-posts are shown in the elevation because they would conceal important parts of the key. The screws B, D, F are connected through the brass rod, steel axles and upright support with a screw that passes through the base and thence by insulated wire with binding-post 4.





Figs. 11 and 12.

The screw B being adjusted so that the upper lever is level, the screw F regulates the amplitude of its movement. By means of this screw it makes contact with the brass stanchion V. The screw E which is insulated from this lever, is connected to post 2 by insulated wire running along the lever, down the standard through the base. The screw U with which it comes in contact is also insulated from its lever and connected in a similar way with binding-post 3. By means of screw D the copper spring S can be made to make contact with screw T which is insulated from its lever and connected with binding-post 6.

The lower lever is adjusted to a level position by screw O; it is insulated from its steel axle and together with screw O is connected with binding-post 7. The screw Z, with which it makes contact, is connected with binding-post 4. So are the brass stanchion Q and the screw N, passing through it, as well as the mercury cup W. The

screw E is so regulated that just before F makes contact with V the lever I breaks contact with the screw Z and immediately after makes contact again in the same circuit either through the screw N or the mercury cup W.

We have six contacts: three makes, two breaks, and one break followed by a make in the same current. One of these breaks, if used at all, must always come first and one of the makes, if used at all, must always come last. According to actual count this gives forty-four different ways in which currents can be passed through the key. When more than one current is being passed through the upper lever at the same time, care must be taken to have this lever connected with the same pole of all the batteries.

A few of the uses to which this key may be put will be mentioned here together with the contacts used in each case.

1. As an ordinary key where the contact is made by pressing down the key; circuit through E-U or F-V.
2. As an ordinary key in which the contact is broken by pressing down the key; circuit through B-P or O-Z.
3. To close two circuits at the same time; E-U, D-T.
4. To close to circuits at the same time and one an instant later; D-T, E-U, F-V.
5. To close one circuit and break another at the same time; E-U, O-Z.
6. To close two circuits and break a third at the same time; E-U, D-T, O-Z.
7. To break one circuit just before closing a second; B-P, E-U.
8. To break a circuit and an instant later close the same circuit again; O-Z, R-N, or I-W.

In the second method of recording reaction-time on the smoked drum, according to the arrangement of wires in fig. 13, the tuning-fork current is short-circuited at P-B while the key remains closed. When this contact is broken, the current passes around through the marker on the drum. A moment later the contact E-U closes a telephone-circuit which passes through the apparatus in the reaction-room and so produces the stimulus. But the primary current of the spark-coil is passing through O-Z. At the same instant in which the contact E-V is made, this contact O-Z is broken and a spark passes through the smoked paper. This primary circuit is made again at W in time to be broken a second time by pressure upon the key in the reaction-room. As soon as this reaction takes place the operator releases the multiple-key, the tuning-fork curve is short-

circuited again at B-P and the time marker ceases to vibrate. As the reaction always follows the contact E-U within three-tenths of a second, the key need not be kept open longer than is natural in slow movement.

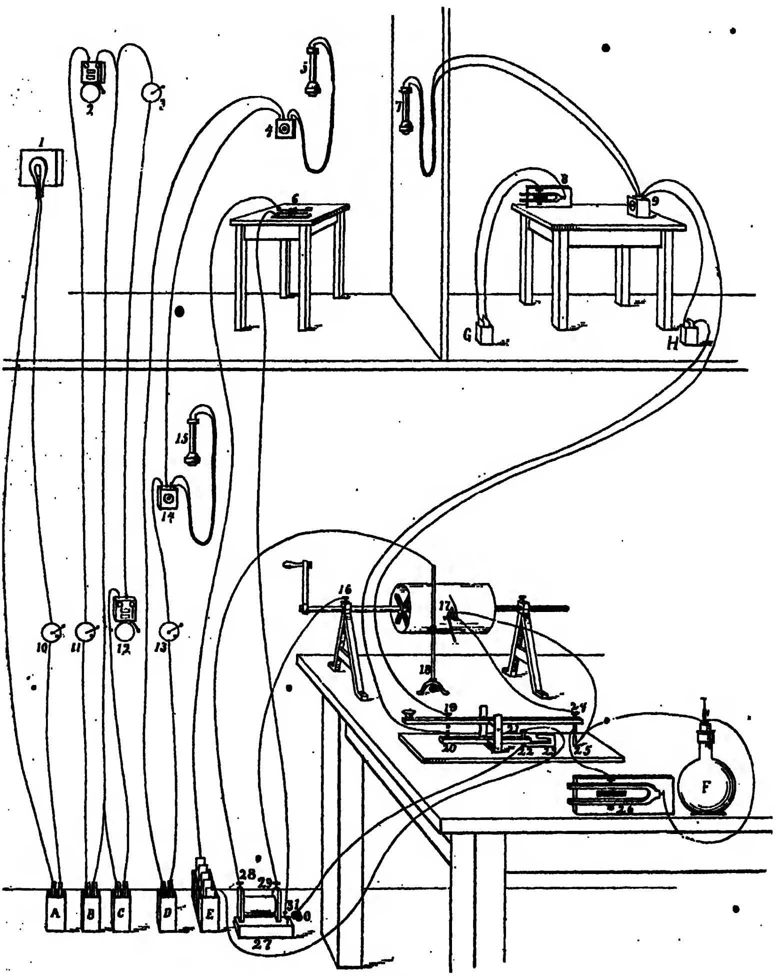


Fig. 13.

The most important pieces of the apparatus having been described in detail, its general arrangement can easily be understood from the diagram in fig. 13. The reaction-room is indicated above on the left. The room used for the production of sound stimuli is shown next to it, although it is situated in another part of the building so that

no sound from the loud tuning-forks can penetrate the walls of the reaction-room. The recording-room is on the floor below. These figures are all diagrammatic, being drawn to show the meaning of wires and apparatus rather than actual positions or proper proportions.

Taking the diagram from left to right, the first pair of wires belongs to an electric light circuit. The lamp 1, which was used in these experiments, was a miniature incandescent lamp of 6 c. p. By a switch, 10, the light could be turned on or off.

The next three wires connect two electric bells, 2 and 12, with the Leclanché elements B and C. Closing key 3 rings the bell in the recording-room. The gong being removed from bell 2 and the contact made permanent, closing key 11 only produces a click in the reaction-room. Otherwise the sound would be so loud as to distract the person reacting.

The next pair of wires forms a telephone-circuit by means of which the experimenter can talk freely with the person in the reaction-room. The switch 13 breaks this circuit during a series of experiments and so prevents any noise reaching the reaction-room through this telephone. This telephone connection is a new feature in reaction-time apparatus and its advantage cannot be overestimated. In some of the German laboratories the reactor and experimenter are in the same room, separated only by a cardboard partition. The reactor is thus influenced by every sound in the building, by the changing lights and shadows and by the noise of the chronoscope. In other laboratories the reactor is placed in a separate room in another part of the building. When the operator desires to speak to the reactor he must leave his work and go to this room, often breaking up the whole series and producing more or less distraction. With this arrangement the reactor is in a dark room, free from sound. By a turn of the switch he can hear even a faint whisper from the experimenter.

Next on the diagram comes a one-inch Ritchie spark-coil; 31 and 30 are the poles of the primary circuit. The current from battery E, consisting of two to four Grove cells, passes through the closed key 6 in the reaction-room and through the contact 21-22 in the multiple-key (O-Z of fig. 11). When the key is pressed down the circuit is broken at 22 and closed immediately after at 23. In practice it was found better to use the mercury cup W, fig. 11, for this second contact as the contact with the copper spring and iron screw R, is a sliding contact liable to produce additional sparks and thus to con-

fuse the record. The mercury must be kept covered with water as alcohol takes fire with a current of the size used.

The poles of the secondary coil are 28 and 29. One was connected with the brass cylinder of the drum by being attached to the iron frame at 16, the other with the point which marks on the drum. When the electro-magnetic time-marker was used, a light aluminium point was substituted for the ordinary straw or quill point. Every time either key is pressed a spark passes from the marker to the drum through the smoked paper scattering the smoke and making the white dots shown in figs. 6–10.

Numbers 19 and 20 are two ends of a second telephone circuit. H is the battery, 9 the transmitter and 7 the receiving telephone. Before the transmitter there stands a tuning-fork 8 run by the battery G. When the multiple-key is pressed down, this telephone circuit is closed at 19-20 and the tuning-fork is heard in the telephone in the reaction-room. At the same instant a spark is made on the drum by the breaking of contact 21-22. The strength of this sound was regulated by passing the telephone-current through a resistance-board, not shown in the diagram. For purposes of simple reaction it was not necessary to use tuning-fork 8. The short, sharp click made in the telephone by closing the circuit at 19-20 was sufficient. By changing the resistance in the telephone-circuit this sound could be varied from one too weak to be heard to one too loud to be endured. It was found necessary to run the wires of this circuit from the recording-room to the reaction-room without allowing them to come near any other wires which were in use at the same time. Otherwise sounds were produced in the telephone by induction from the currents in those wires.

During the latter half of the experiments the two receiving telephones, 5 and 7, in the reaction-room were each connected with both transmitters, 4 and 9. By this arrangement the sounds from the recording-room and from the sound-room were heard in each telephone. One of them was fixed by rods and clamps in such a position, that the right ear of the person experimented upon naturally rested against it. The other was held to the left ear by the left hand, while the right hand was free to manipulate the reaction-key.

A still better plan would be to use a head telephone with a receiver at each ear. This would always be in place, leave both hands free and allow the person reacting to take the most comfortable position and to move about instead of keeping the body in one fixed position. However, as a series of experiments never lasted over five

minutes, the disturbance from the act of holding one of the telephones cannot have been very great.

The remaining wires shown in the diagram all have to do with the time-curve. The tuning-fork 26 is run by a dip-battery F. This current passes through the contact 24-25 when the key is closed as shown in this figure. When the key is opened, this contact is broken and the current passes around through the electro-magnetic time-marker 17 communicating to its lever the vibration of the tuning-fork.

In most of the experiments made with the hand-drum this time-marker was not used. The fork itself was placed on the standard and allowed to vibrate continuously on the smoked paper.

In addition to the wires shown in the diagram another pair was used to connect an electro-magnet in the reaction-room with a battery and switch in the recording-room.

All of these wires are part of a system of wires running through the whole building. At first seven wires were laid from each room to a switch-board in a central position. This number not being sufficient for the currents required between the reaction and recording-rooms seven more were laid to each of these rooms. All of these wires where the resistance is of small importance, such as the telephone and bell circuits, are number 16 B. and S. office wire. For the electric light and the primary circuit of the spark-coil, where stronger currents are required, number 10 heavily insulated wire was put in. These were run directly from the reaction-room to the recording-room independent of the switch-board.

Experiments in reaction-time.

In all the experiments the stimulus to which the person in the dark room reacted was a sound produced in the telephone.

A warning click was given on the bell in the reaction-room just before each experiment. Experiment has shown that when the interval between warning and stimulus is always the same the mind is soon able to estimate the interval correctly and always reacts just at that time whether it hears the stimulus or not. Therefore this warning cannot be produced by any mechanism connected with the drum but must be given by the voluntary act of the experimenter. The effect of this warning on the reaction-time depends on the interval between the warning and the stimulus. If the interval is too short there is not time enough to concentrate the attention and the warning hinders the reaction instead of helping it. If the time is too

long the effect dies away, as the mind is not able to keep its maximum tension for more than one or two seconds. L. LANGE[1] mentions about 2 seconds as the best interval. WUNDT[2] places it at 2.5; Estel[3] says 2.25; MEHNER[4] and GLASS[5] agree on 2.5. BERTELS[6] found that it took the mind 2⅝ seconds to reach the maximum degree of attention. The interval used in these experiments was 2½ seconds; as nearly as the experimenter could estimate it by counting.

Much also depends upon the interval between the successive experiments. If it is too long the series covers too much time. Changes in the mental and bodily condition of the experimenter come in to change the reaction-time. If the interval is too short there is not time to recover from the preceding experiment. About fifteen seconds was the interval between the successive experiments in the present case. As reaction requires close attention, not more than twenty-five experiments can be taken at one sitting without showing marked effects of fatigue. In the larger part of these experiments the number was limited to twenty-two and at least five minutes intervened between successive series. Seldom were more than five series taken at one time.

An important point in which there is less agreement is that of the rejection from the records of unusually long or short times. These have usually been regarded as errors and ascribed to two sources, to a faulty action of the electro-magnet in the Hipp chronoscope, and to inattention on the part of the reactor. The present apparatus eliminates the former error but the latter still remains. Inattention may give long times and the person may react before he actually hears the stimulus. By keeping a careful watch most of these cases will be noticed on the spot and be rejected without question as errors. But still the tables will contain an occasional long or short record which largely affects the average of the series. What shall be done with these cases? Some have refused to omit any, claiming that individual differences disappear in the final average. Most writers use their judgment in each particular case and reject all records which they think unduly affect the results. It is always hard to draw the line between normal attention and the next grade below it, to decide

[1] *Beiträge zur Theorie der sinnlichen Aufmerksamkeit*, Phil. Stud. 1888 III 492.
[2] Physiol. Psych. 3 ed. II 361.
[3] *Neue Versuche über den Zeitsinn*, Phil. Stud. 1885 II 37.
[4] *Zur Lehre vom Zeitsinn*, Phil. Stud. 1886 II 560.
[5] *Kritisches und Experimentelles über den Zeitsinn*, Phil. Stud. 1888 IV 454.
[6] *Versuche über die Ablenkung der Aufmerksamkeit*, Inaug. Diss. Dorpat 1889.

which are correct reaction-times and which are errors. The purpose of the experiments may have an influence in deciding this question. For instance, if it is to get the average reaction-time of a certain person in a series lasting five minutes, then more marked cases of inattention would be expected and let pass unchallenged than if the purpose was to detect the influence of a slight distraction on the reaction-time. In the former case the variation in attention is the quantity to be measured. In the latter case it is desired to eliminate all variations in the attention save that due to the one cause whose effect is being investigated.

In the present instance every record was rejected which seemed to the *reactor* to be a mistake. His opinion was always written down before he left the reaction-room and before he knew what the figures were. After that the criterion for rejecting readings was that laid down by HOLMAN.[1] "Take the mean and the average deviation of the observations, omitting the doubtful one. Find the deviation of that one from the mean. Then reject the observation if its deviation is greater than four times the average deviation." This is an arbitrary criterion and does not imply that all records rejected by it are errors. It means rather that in the small number of records they would have undue influence and that the average without them will be nearer the truth than if they were included.

In every case excepting the few series where the names are given in the table the writer was the person experimented upon.

EXPERIMENTS SHOWING THE INFLUENCE OF SENSATIONS OF LIGHT UPON THE TIME OF SIMPLE REACTIONS TO SOUND.

The first problem undertaken was the investigation of the influence of the presence in consciousness of different colored lights upon the time of reaction to sound-stimuli. It was suggested by the results of FÉRÉ's experiments with the dynamometer.[2] He found that with hysterical patients different colored lights had different dynamogenic effects, red being most effective and violet the least. If the energy with which the muscles can be contracted varies with the appearance in consciousness of different colored lights it seems probable that there should be a similar effect upon the rapidity with which they can be moved.

---

[1] HOLMAN, Discussion of the Precision of Measurements, New York 1892, p. 30.
[2] FÉRÉ, Sensation et mouvement, Paris 1887.

These experiments are not to be confused with those conducted by TITCHENER in Wundt's laboratory where different colored lights served as the stimulus.[1] The effect of a steady influence might be detected when the effect of a momentary influence was too small to be measured. We certainly have a different tone of feeling when looking at a red light from that which we have when looking at a green light.

The different colored lights were produced by colored gelatine films between two pieces of glass placed before the box containing the electric light.

Three hundred experiments were made upon this point, but they must be regarded as preliminary and negative. They were made upon six different persons all of whom were without practice in reacting, and, as they were taken before the apparatus was completed, the method illustrated in fig. 3 was used, the error of which has already been pointed out.

The results show no difference for the different colors within the limits of error and none between those taken in the dark and those in the light. However, in all cases they show the effect of practice on reaction-time. Table I brings this out in the case of two persons, the first one of whom reacted several thousand times in the interval

TABLE I.

Name	Date	R	MV	*n*
C.B.B.	Nov. 13.	183	34	90
"	Mar. 31.	140	13	236
J.A.G.	Dec. 1.	250	36	59
"	Jan. 30.	161	22	28

R, reaction-time.
MV, mean deviation.
n, number of experiments.

between the two dates given while the second reacted only a few times between the dates for which his reactions are compared. In the

[1] *Zur Chronometrie des Erkennungsactes*, Phil. Stud. 1893 VII 140.

case of the first person an average of 90 experiments taken on Nov. 13, gave a reaction-time of 183^{σ} and an average deviation from that average of 34^{σ}. On March 31 an average of 236 experiments gives a reaction-time of 140^{σ} with an average deviation of $13.^{\sigma}$ Thus showing not only a great falling off in the time but also a great increase in the regularity of the experiments.

A like result is shown in the record of the second person.

From these figures it is plain that we are not to expect differences due to small changes in the conditions of the experiments to show themselves until the person experimented upon has had some practice.

One other set of experiments was taken before the apparatus was accurate to thousandths of a second. These were all made upon one man, the object being to see whether, with the degree of accuracy then obtained, any difference could be detected between the time of reactions taken in the dark and those taken in the light. The averages of the separate series are given in table II. The final average of 115 experiments in the dark gives a result of 170^{σ} with a mean variation of 23^{σ}. The 74 experiments taken in a white light

TABLE II.

Disturbance	R	MV	n
None	170	23	115
White light	177	30	74
Red light	175	25	20
Green light	160	15	20

give a time of 177^{σ} with a mean variation of 30^{σ}. The 20 experiments in red light give a time of 175^{σ} with a mean variation of 25^{σ} and the 20 experiments in green light give a time of 160^{σ} with a mean variation of 15^{σ}.

After the apparatus was correct to thousandths of a second, another attempt was made to detect a difference between the time of reactions in the dark and those in the light. A series of twenty or thirty experiments was taken in which the light was turned on in the mid-

dle of the series. Table III gives the average of five experiments before the light was turned on and five immediately after. The experiments were taken upon seven different persons only two of whom had had experience in reacting and only one of whom had had practice that year. Considering this and also the fact that only five series were taken upon any one person, too much confidence must not be placed in the results. It would be very easy to say that they show the distracting influence of the light; for in the case of each individual, save one who had had no practice and upon whom only one series was taken, the average of the reactions in the light is longer than those in the dark.

TABLE III.

Person	D	MV	n	L	MV	n	L - D
D. W. L.	148	15	15	150	11	15	+2
C. B. B.	147	7	25	151	9	25	+4
E. W. S.	184	28	25	191	24	25	+7
J. M. M.	159	12	5	191	24	5	+32
W. I. C.	146	16	20	156	9	20	+10
K. M. W.	119	30	10	139	16	10	+20
J. A. G.	181	28	5	171	15	5	−10
Weighted mean	153	18	105	160	14	105	+7

D, reaction-time in darkness.
L, reaction-time in light.

The final average of the 210 experiments is 153^σ for the dark with a mean variation of 18^σ and for the light 160^σ with a mean variation of 14^σ. But later and more reliable experiments show that the mere presence in the field of vision of this steady light would not produce that effect. A glance at the original records throws some light on this point. In eight of the series the first reaction after the light was turned on was unusually long. In the nature of the case these

records could not be rejected, for though there is a possibility that they may be due to inattention yet it is far more probable that they are the very thing we are looking for. When the light is turned on it startles the person for an instant and so increases the reaction-time. Table IV shows this fact very clearly. It contains the first, second, third, fourth and fifth experiments before and after the light was

TABLE IV.

Person	Dark					Light					n
Number of exper.	*5.*	*4.*	*3.*	*2.*	*1.*	*1.*	*2.*	*3.*	*4.*	*5.*	
D. W. L.	181	153	141	128	140	149	171	144	146	139	3
C. B. B.	139	150	132	153	150	158	145	142	156	153	5
E. W. S.	175	179	172	147	202	178	187	192	177	223	5
J. M. M.	165	151	155	138	139	248	194	167	166	179	1
W. I. C.	135	154	139	158	140	198	150	142	163	123	4
K. M. W.	114	131	103	135	108	151	122	118	136	167	2
J. A. G.	183	148	123	299	153		197	177	176	134	1
Weighted mean	154	156	142	153	155	165	162	155	160	166	

turned on in each series, so arranged as to show the averages for the first, second, third, fourth and fifth experiments in the case of each individual and also the final average of all together. In the final average and in the case of most of the individuals, notably in the case of those who were practiced, the first experiment after the light was turned on was longer than the other and enough so to affect the averages in table III.

When the light was turned on, no care was taken to have it come exactly half way between two experiments. Sometimes it would be nearer the one before, sometimes nearer the one which followed. This may explain the reason why some of the series show no distraction. The light was turned on in the early part of the interval

and the person had time to accommodate himself to it before he heard the stimulus. Doubtless if the interval between the moment of turning on the light and that of the reaction immediately following it were carefully measured it would be found that this first reaction would be lengthened the more the smaller this interval.

The next attempt to detect a difference between the time of reactions in the dark and those in the light was made later on in the year, after considerable practice. In the experiments already described the electric lamp was carefully concealed in a box, the sides of which were lined with tin reflectors, so that the person sitting at the reaction-table saw only a brightly illuminated square of white card-board in the back of the box. Since the effect was so slight the box was dispensed with in these later experiments and the lamp hung suspended in full view. The method was the same as in the former case, except that the order of light and dark was reversed in some of the series to eliminate any effects from fatigue or acceleration which might enter into a series of twenty experiments.

The total number of experiments was 207, consisting of 97 in the dark and 108 in the light. Of the ten series, six gave a slightly longer time for those in the light while the other four gave an equally small difference in favor of those in the dark. The final averages are: for those in the light, 138^{σ} with a mean variation of 12^{σ} and for those in the dark 136^{σ} with a mean variation of 10^{σ}, thus showing a difference of only 2^{σ} both in the reaction-time and in the mean variation, a difference which is practically zero. These figures then warrant the statement that *the difference between reaction-time in the dark and reaction-time with the eyes fixed upon a bright steady light is very small compared with the constant variation due to subjective changes in the condition of the person experimented upon.*

After it was found that the presence of a steady intensely bright light in the field of vision produced no variation in the reaction-time which could be detected, it was decided, at the suggestion of Professor Ladd, to study the effect of a moving light.

The small incandescent lamp was suspended from the ceiling by a flexible cord about six feet long. Just above the lamp a piece of soft iron was fastened to the cord. This iron served two purposes: it made the lamp swing steadily and allowed it to be held in position by an electro-magnet fastened to one end of the room. The electric light current and that of the electro-magnet were then both passed through the same switch in such a way that one movement of the lever broke the electro-magnet current and turned on the light.

Ten experiments were taken in the dark ; then the operator turned the switch and the person experimented upon had a steadily swinging light in his field of vision. In addition to the moving light there was always a great variety of moving shadows and changing intensities as the lamp swung past the wires, standards and other parts of the apparatus. When the light was turned on, the eye invariably followed the lamp for one or two minutes, after which the shadows came into consciousness, then the objects which produced the shadows and finally other things in the room.

The amplitude of the motion was regulated by moving the electro-magnet. During part of the experiments the lamp commenced to swing through an arc of two meters, which gradually diminished during the experiment to half a meter. In the rest of the experiments the arc was half a meter at first and the lamp gradually approached a state of rest. Had the results warranted, a more careful determination of this amplitude would have been made. In these experiments the order of light and dark was changed to eliminate other influences. It was of course impossible to stop the lamp swinging in the middle of a series, but the light could be turned out.

The mean variations are fairly low and regular. Therefore the results may be regarded as quite trustworthy. In twelve out of the sixteen series the reaction-time while looking at the swinging light was from 2^σ to 20^σ longer than the reaction-time in the dark. The final averages for those in which the long swing was used were : in the dark, 137^σ with a mean variation of 13^σ ; in the light, 142^σ with a mean variation of 11^σ. For those with the short swing they were : dark, 142^σ, mean variation 12^σ; light, 147^σ, mean variation 12^σ. No difference can be detected between the influence of the long and short swings. Combining the two we have as a result of 363 experiments a mean variation of 12^σ for those in the light, the same for those in the dark, and an average of 142^σ for the reaction-time in the dark and 147^σ for the reaction-time when looking at a swinging lamp.

It is important to discover if possible whether this disturbance is uniform throughout the ten experiments with the swinging light, or whether it is confined either, as in the earlier experiments, to the first reaction after the light was turned on or to those first few experiments where the eye follows the moving light. For this purpose the averages of the first, second and third experiments and so on of all the sixteen series were calculated and found to be, before the light was turned on, (1) 145^σ, (2) 143^σ, (3) 144^σ, (4) 145^σ, (5) 142^σ, (6)

139$^\sigma$, (7) 144$^\sigma$, (8) 144$^\sigma$, (9) 135$^\sigma$, (10) 140$^\sigma$; after the light was turned on, (1) 154$^\sigma$, (2) 149$^\sigma$, (3) 148$^\sigma$, (4) 142$^\sigma$, (5) 144$^\sigma$, (6) 151$^\sigma$, (7) 151$^\sigma$, (8) 139$^\sigma$, (9) 140$^\sigma$, (10) 143$^\sigma$. This shows conclusively that the chief disturbance is found in the three reactions after the light is turned on. The greatest lengthening is in the first reaction. Part of that is certainly due to the same effect which was noticed in table IV, namely to the distracting effect of having the light suddenly appear. But the presence of a similar though less effect in the next two averages shows a distinct influence from the moving light after the first surprise is over. Therefore we infer that part of the lengthening in the first reaction with the swinging light is also due to the moving light.

Later on in the series there is one average which is nearly equal to the first one with the light but an examination of the individual experiments shows that this is due to the accidental presence in that average of four unusually long times.

From these experiments we conclude that *the influence of light sensations upon the time of reaction to sound is comparatively small when the light is steady, but becomes very marked as soon as the light begins to move.*

A practical application of this fact suggests itself at once. There is no advantage for purposes of simple reaction in having the room dark. But it should not be lighted by a window, else moving shadows and changing intensities will affect the reactor. It must not be lighted by a lamp or gas jet for they would each, in the case of a small room at least, raise the temperature or, in case the room were ventilated by a current of air, be made to flicker and so distract the attention. But when the conditions of the experiment do not require a dark room there can be no objection to the presence of an incandescent lamp. On the contrary the person experimented upon will feel more at ease in a lighted than in a dark room and will find it much easier to make notes of any important points which occur to him during the experiments.

Experiments showing the influence of sensations of sound upon the time of simple reactions to sound.

The experiments thus far described have had to do with the influence of sensations of light on the time of reaction to sound. A similar set of experiments was conducted for the purpose of investigating the effect of sensations of sound on the time of reaction to

sound. In the first place the sound used was a steady tone produced by an electric tuning-fork vibrating 250 times a second. This tuning-fork was placed on a shelf before the transmitter in the recording-room and run by a dip battery. When the telephone circuit was closed this tone was sent to the reaction-room and, when the two receiving telephones were connected together, was heard in the same telephone in which the signal to react was heard. The moveable drum shown in the diagram makes no noise and, when the operator is careful and the rest of the building is quiet, no sounds reach the ear of the reactor through this telephone save those of the tuning-fork and the signal to react. The tuning-fork sound is so loud that none of the fainter sounds in the building or on the street can be heard. This method could not be used with the electric drum on account of the noise of the motor, except by placing the transmitter and the fork in another room.

The method of experiment was similar to that employed in investigating the influence of light-sensations. Ten experiments were taken in silence, then the telephone circuit was closed and during the remainder of the series the person heard the steady tone of the tuning-fork in the same ear in which he heard the stimulus. In successive series the order of silence and sound was changed to eliminate the influence of sequence. After eight series had been taken the method was slightly varied. It was evident that as in the case of the steady light the disturbance was very small. It was thought that possibly, as in the case of a steady light, the influence would be greatest upon the first reaction after the sound was turned on. Therefore to get the full effect of this influence, instead of taking ten experiments in silence and ten more with the tuning-fork sound in consciousness, one experiment would be taken in silence, then the tuning-fork sound turned on for the second reaction, while the third would be in silence and so on through the series. In each case, however, the tuning-fork was turned on immediately after the reaction in silence, thus giving about ten seconds for accommodation before the signal to react.

By changing the intensity of the telephone-current the loudness of the tuning-fork sound was varied at will. For the purposes of these experiments it was kept as nearly as possible equal to that of the sound which served as the signal to react.

Table V gives the averages of all these series. In it no difference can be detected between the time of reactions in silence and those in which the tuning-fork was heard. Seven of the individual series

from which this table was compiled showed a slight difference in favor of silence and nine showed about the same difference in favor of those with the sound. Of those where silence and sound alternate the same thing is true. Four were longer in silence and five in sound. The final average gives a time of 153^σ and a mean variation of 19^σ for those in silence and a time of 152^σ with a mean variation of 18^σ for those with sound. The average for the writer was 141^σ for silence with a mean variation of 15^σ and for sound 139^σ with a mean variation of 16^σ, showing a slight difference in the same direction as the combined results of the three persons.

TABLE V.

	Silence	MV	n	250 fork	MV	n
C. B. B.	141	15	104	139	16	113
W. I. C.	167	26	33	174	22	33
A. F.	232	42	10	242	39	8
Weighted mean	153	19	147	152	18	154

When it was found that the presence in consciousness of a steady tone produced no appreciable effect upon the reaction-time, with the skill in reacting thus far obtained, it was thought best to try the influence of an intermittent sound, as in the former experiments a moving light took the place of a steady one. The most convenient instrument which suggested itself for this purpose was the metronome. SWIFT[1] investigated the effect of the ticking of the metronome upon discrimination-time and found different results according to the rapidity with which the metronome ticked. He also found that it lengthened the time of simple muscular reaction. In a series of 100 experiments he found the reaction to be 103^σ, with a mean variation of 9^σ, whereas 100 experiments taken while a metronome was ticking in the room gave 122^σ, with a mean variation of 12^σ.

During the first few experiments the metronome was placed in the reaction-room and so arranged that the pendulum was held to one

[1] SWIFT, *Disturbance of the attention during simple mental processes*, Am. Jour. Psych. 1892 V 8.

side by the electro-magnet until the circuit of the magnet was broken in the recording-room. Thus the metronome could be started at will during the series. But in the small reaction-room the sound was almost too loud to be endured. It was found more satisfactory to place the metronome on the shelf before the transmitter in the recording-room, as had been done with the tuning-fork. Here the operator could stop the sound as well as start it and could regulate the intensity so that it should be about the same as that of the stimulus. There was an advantage also in having the two sounds come in exactly the same direction.

The order was the same as before, ten experiments in silence, then ten with the sound and vice versa. In different series the metronome ticked 40, 80, 120, 160 and 200 times a minute. Table VI gives the averages for each of the rates.

TABLE VI.

Rate of Metronome	0	40	80	120	160	200
Reaction-time	152	156	184	186	179	169
Mean variation	18	17	26	20	20	25
Increase	0	6	32	34	27	17
Number of experiments	147	28	54	93	61	42

In the first experiments where the metronome was in the reaction-room, there was a great innervation and strain in all the muscles of the body called forth to withstand the influence of the metronome. This was not noticed while the metronome was ticking, but the moment it stopped the sudden relaxation was very evident.

At the beginning of the experiments there is a marked change due to getting acquainted with the sound but, owing to the short duration of the experiment, that influence does not continue after the first surprise has worn away. Judging from the complete inattention to a clock ticking in my room it is probable that after listening to a metronome tick for a few hours it would no longer affect the reaction-time. The stopping of the metronome might then have a temporary effect. Indeed, in these experiments the reactor soon be-

came so far accustomed to the sound that an occasional vibration of the metronome spring, just loud enough to be heard, seemed more distracting than the metronome itself.

From these experiments we conclude that *the influence of a sound-sensation upon the time of reaction to sound-sensation is very small as long as that sound is a steady tone but becomes very marked when the sound is intermittent.*

Experiments showing the difference in the time of reaction to sounds when the sound is heard in two ears instead of one.

It has already been suggested that the best way to produce a sound-stimulus for purposes of reaction is to use a head-telephone with a receiver at each ear. The following set of experiments were taken to show the relation between the time of reactions when the stimulus is heard in one ear and the time of those in which the same stimulus is heard in both ears.

The arrangement of the telephones has already been described. The method of experiment was similar to that of the experiments which have been described above. The person reacted ten times with a telephone at only one ear, then without interrupting the series he placed the second telephone at the other ear and continued to react ten times more. To eliminate other influences the order was sometimes reversed and the first half of the series taken with the sound in both ears.

Table VII gives the average of twenty-one series taken in this way. With the exception of three cases, where the person had no experience, the reaction to the sound in both ears is much shorter than that of the reaction to the same sound in one ear. The average of the thirteen series upon the writer, who was the only one having experience in reacting, with the exception of Dr. Scripture, give for one ear a time of 147^σ and a mean variation of 19^σ, for two ears a time of 133^σ with a mean variation of 19^σ. The number of experiments with one ear was 108, with two ears 123. The average of eight series taken on four other persons gives for one ear a time of 207^σ with a mean variation of 38^σ, for two ears a time of 188^σ with a mean variation of 31^σ. The number of experiments with one ear was 83, with two ears 82.

A natural explanation of the difference between the reaction-time when the signal is heard in one ear and the reaction-time for the same signal heard in two ears would be found in the difference in

the intensity of the sound as heard in the two ways. In order to see whether this explanation was satisfactory or not, fifteen series of experiments were taken in which the stimulus was varied in intensity from a loud to a weak sound.

This change of intensity was secured by introducing a resistance-box into the telephone circuit. The battery then in use consisted of twelve gravity elements. With the normal resistance of the circuit they gave a current of 0.5 amperes. With an additional resistance of 100 ohms the current was reduced to 0.08 amperes and the click made by making the circuit was a weak sound compared with that heard in the telephone when the normal current was used. Yet it was a sound which could be distinctly recognized. A switch was so arranged that by a turn of the lever the resistance box could be brought into the telephone circuit.

TABLE VII.

	One ear	MV	n	Two ears	MV	n
C. B. B.	147	19	108	133	19	123
E. W. S.	269	58	17	199	38	20
T. J. L.	182	35	39	175	26	33
W. I. C.	192	29	15	201	33	39
Weighted mean	170	27	179	158	24	215

The average for 132 experiments with the loud sound was 143^{σ}, with a mean variation of 13^{σ}. The average of 126 with the weak sound was 153^{σ}, with a mean variation of 16^{σ}. The difference between the loud and weak sound was 10^{σ}. That between one and two ears was 6^{σ}.

Attention might be called in passing to the fact that in this set of experiments four series were taken in which the succession of loud and weak intensities was irregular. The experimenter was told to make it as irregular as possible. The average of these four series for the loud sound is 143^{σ}, for the weak sound 155^{σ}. The mean variation from the average of the whole set is, for the loud 16^{σ}, for the

weak 17^σ. The number of reactions to the loud sound was 64 to the weak sound 66.

These figures are in marked contrast to those of Wundt. With him 18 successive reactions to a strong sound gave a time of 116^σ with a mean variation of 10^σ. A set of 9 reactions to a weak sound gave a time of 127^σ with a mean variation of 12^σ. When the succession of loud and weak sounds was irregular the time for the loud sound was 189^σ, mean variation 38^σ, number of experiments 9. The time for the weak sound was 298^σ, mean variation 76^σ, number of experiments 15. The increase due to irregularity in his case amounts to 114^σ, in our case to 12^σ.

It can scarcely be that there was a greater difference between the sounds he used; the difference in the present case was so great that the loud sound, when the order was unknown, was greatly dreaded and always produced a decided shock.

There are two other series of experiments which are worthy of note, having been taken without warnings. Their average for forty experiments is 139^σ, mean variation 26^σ, whereas the average of the thirteen series taken on the same person under the same conditions but with the warning was 140^σ with a mean variation of 19^σ; total number of experiments 231. Wundt's figures on the same point are, with warning 125^σ, without warning 259^σ, total number of experiments, 61.

We have shown that a large part of the difference between the time of one and two ear reactions is due to the difference in intensity. But to test this point more closely another set of experiments was taken in which this factor was entirely eliminated, yes, more than eliminated. The reaction-time of one and two ears was compared as in the last set but at the same time the intensities of the currents were varied so that the sound heard in one ear was judged to be much louder than the combined result of a weaker sound heard in both ears. If intensity be the only factor in producing the difference between one and two ear reactions then the reaction under these conditions ought to be much longer for one ear than for two. In only two series was there any marked difference between the two. One of these is in favor of the loud sound in one ear the other in favor of the weak sound in two ears. The difference between the final averages of the ten series is only 1^σ, practically 0.

Therefore: *the reaction-time to sounds heard in two ears seems to be shorter than for the same sound heard in one ear even after due allowance has been made for difference in intensity.*

In all of these experiments the sound in two ears was located in the upper interior part of the head. Turning the attention toward the sound resulted in rolling the eyes upward ; the sound seemed closer at hand and less effort was required for reaction than when the stimulus was heard in only one ear; the reaction also seemed more automatic, especially when the attention was turned to other things.

CONCLUSIONS FROM THE THREE PRECEDING SECTIONS.

The general results of these experiments in reaction-time can be summed up as follows:

1. The experiments did not indicate any difference in reaction-time produced by changing the color of the light present in the field of vision.
2. No difference was detected between the times of reactions in the dark and those made while looking at a stationary incandescent light of six candle power.
3. When this light was in motion the reaction-time was lengthened.
4. No difference was detected between the times of reactions in silence and those made while listening to the steady sound of a tuning-fork making 250 vibrations per second.
5. When the intermittent sound of a metronome was substituted for that of the fork, the reaction-time was lengthened.
6. The reaction-time to a sound heard in both ears is shorter than when the sound is heard only in one ear, even after making allowance for the difference in intensity.

INTROSPECTIVE OBSERVATIONS ON REACTIONS.

During the larger part of the experiments pencil and paper were kept in the reaction-room and immediately after each series of experiments the person reacting noted down any conditions liable to affect the time of his reaction and any observations which might throw light on the nature of reaction-time. These notes were afterwards transferred to the record blanks just below the records to which they referred in order that these records might be used more intelligently.

A careful study of the notes together with the records to which they refer brings out many interesting points. Not all of them can be touched upon here but the most important ones will be found below substantially as they were written down from day to day.

After a few weeks practice reacting becomes so much a matter of habit, that trying to recall what has taken place during a series is like trying to remember dreams. The more striking points are easily retained but the larger part of the points which are noticed during the series are gone beyond recall unless they are noted down within a few minutes. A little practice enables one to record all mistakes in reacting, all reactions to warnings, all reactions registered before the signal is heard and all cases where the reaction-time is greatly lengthened by a physical or mental disturbance.

NOTES MADE IN THE REACTION-ROOM IMMEDIATELY AFTER EXPERIMENTS.

The following abbreviations are used :

W=Warning.
R=Reaction.
M=Muscular.
Att=Attention.
"fore"=Reaction before the signal.
Met=Metronome.
Om=Omitted.
a=first, b second half of a series.

The figures are taken from the original records for comparison with the notes. The numbers of three figures are reaction-times, those of one or two figures are mean variations. Where two sets of figures are given the first pair is the first half and the second pair the second half of a series. When the note refers to a particular experiment that one is compared with the rest of the series and its figures are given first. In order to make the meaning of the notes clearer explanatory remarks have been added; these are distinguished by italics.

1. R. to light.
2. Sounds heard outside.
63. Irregularity due to novelty of M. (134-6—138-17). *Showing that the irregularity was over-estimated.*
65. Turn Att.=turn eye.
76. 6, 8-11. React with jerk. (133—135-8). *The average of these four is 2σ shorter than that of the rest of the series.*
78. React with full arm movement. (138-13—137-28).
79. R. to W.
82-4. Tired, nervous, slow. (134-26—118-20.) *Mistake in judgment.*
94. W. I. C. "No difference." (209-22—181-31.) *Showing lack of practice.*
95. Notice regularity with two ears. *The figures don't show it.*
96. a. 1. React in spite of resolve. (222—197-26.) *A purely automatic reaction, extra long.*
96. Trying to think ot Schopenhauer. (200-27—179-24.) *At least 50σ longer than the normal reaction-time.*
99. One R. before will impulse.
98. R. to W.—b, 1, om. in relaxation of silence. Sound terrific. (Silence 133-7—with sound 133-10.) *No effect from this very loud tuning-fork sound.*

100. a, usual way, b, tense muscles. (146–33—120–16.) In one case will didn't overcome pressure. Att. confused in learning a new lesson. *In spite of confusion the reaction with tense muscles are 26σ shorter than the others!*
105. Last four, extra effort. (163—161–10.)
106, 7. Dr. Scripture "Not used to react without W. Have to 'wake up' when only one ear is used." *Two-ear reaction is more automatic.*
108. R. to small sound raises finger but little. *Showing the reflex element in all reactions.*
109. a, 5. R. too weak to raise finger, b, 3 "fore." 7–10, absorbed in plans.
111. a, one "fore." All sorts of distractions, pain in toe, wagon, shadows, thought.
113. Last one quick. Way prepared for motor impulse. (127—156–15.) *Correct estimate.*
114. 9 "fore." Met. very loud, scarcely hear W.
115. R. to W. Last 3 good. First 2 om.
116. Met. gives terrific sound.
119–21. Effort to touch a point 6 in. away.
126. The same. Very quiet; perfect type. b, att. more to muscles. (133–13—139–11.)
128. a, one ear, b, two ears. Two slightly longer. (148–13—142–23.) *Error in judgment.*
127. One om. driven out by another idea. R. to W. Every W. heard with tendency to R.
129. Sensory—M. M. quicker, harder. (129–10—127–9.) *Not enough quicker to be detected.*
130. a., ½. Terrific scraping;=insulation worn off in key. b, Att.=rolling eyes up.
134. 2–1 ear. 2 ear quicker. (127–7—140–15.) *Correct.* a, 9 Automatic. Mind returning from wandering surprised. (124–7—183.)
136. Att. all over, affects nerve force.
137. Loud—faint. Tend to give more Att. to faint sound at first.
141. Att. wandered. (157–17.) *20σ longer than normal.*
142. (153–14—132–9.) } Exercise between 142 and 143. Quick pulse, deep
143. (129–6—127–13.) } breathing. *Shortening the time 24σ.*
144. Careful Att. Sensory (?). Eye turned up. a, 5, long (202). b. 6, long (226). (153–13—170–7).
145. Faint demands, loud compels Att. Att. wandered. (Faint 152–17—loud 132–4).
149. 9, "fore." M. Faint-loud. Don't notice dif. intensity. M=hard work. (150–15—156–31.) *Attempt at muscular reaction a failure.*
150. React best way. Att. good. (168–19—171–8.) *Error in judgment.*
153. Faint-Loud. Irreg. No accommodation, no guessing. (148–16—167–21.)
154. No influence from knowledge of problem. One R. too faint to be recorded.
156. Sound varies from large sound to small short sharp pops=poor contact in multiple-key.
158. 1 ear loud—2 ear week. b, 1 No R.; too weak for one ear.
159. b, 1, loud sound in two ears. Awful start—Quick. (128—141–7.) *A case where the reflex element shortens the time.*

160. Last half thinking of something else. (134–159.)
161. Met. magnet didn't work. Started it myself.
164. Distr. of small sounds more than Met.
171. Reverberation of Met. spring very distr. (160–12—196–21).
172. Head most aches. Not feeling well. W. don't nerve me up. Sleepy. (132–11—156–16).
176. One "fore."
177. Sleepy. Not energy enough to tell what I have done. It was pretty good. (156–17—193–29.) *Error in judgment.*
178. Not so good. Uncomfortable position. Thought distr. more than noise. (172–27—167–13.)
182. Clear mind, like crystal, a sharp frosty morning, or the clear blue sky. (149–16—155–19).
186. Thinking of key. Does it distract? (150–21—196–48). *Decidedly.*
184. Noise of met. board provokes me. (151–8—205–9.) *Showing that irreg. sounds are much more distracting than the metronome.*
195. Two om.; one slow. No light at first. 2–4, one ear. Wagon: Out of patience! (136–8—158–15.)
196. Best yet. (154–12—129–8.) a, 1–6, uneasy. b, first rate; key between fingers.
198. a. Not esp. good. (134–16—146–10.) 2–4, Att. off. 147, 138, 139. *As good as 196.*
204. Some one up stairs. Warning out of order. (151–13—158–12.)
201. Distr. small. (130–7—139–10.)
202. Too fast. Fairly good. (127–10—134–17.) Last 3 thinking of spark. 125, 180, 128.
205. a, 6. Wagon heard on the street. (122—136–13.) *No disturbance shown*—b, 3. Seashore dropped something. (156—139–12.)
208. Seems long. Att. Wanders. (159–15—161–14.) *Decided effect.*
209. Little Att. Not tired. No ability to apply myself. (171–10—151–6.)
206. First rate, last half of b, distr. by wagon because I ought not to hear it. (139–16—156–13.)
207. Not so good. Too excited. b, light steadies me. (143–9—148–17.)
208. Hard to hold att. for 20 experiments. (146–11—162–11.)
209. Impossible to do good work. Think of everything. (138–9—151–13.)
210. Old position, elbow on table. First class example of inattention. Reaction natural in the flow of ideas. (141–13—140–8.)
211. First rate; b, 1, "fore." Innervate finger and fore arm. (132–14—141–11.)
213. Very good. b, end, M. (180.) One before sensory. (129.) Perfectly passive. Not innervation enough to hold the key. (129–8—141-20.)
214. Not quite as good. (121–12—135–15.)
215. Try to get away from bodily feelings=innervate Cortex. (128-7—147–13.)
216. The same. (126–12—145–9.)

The first impression on reading over these notes is one of surprise at the number of experiments in which there is some disturbance of the attention aside from that of the stimulus and warning. No amount of care in the preparation of a reaction-room and in remov-

ing external influences can do away with skin sensations, with muscular feelings, with changes in the physical and mental condition or with the ceaseless flow of thought.

An examination of the notes shows that these disturbances vary greatly. At times they are very prominent; then again they will be scarcely noticed. Record 196 is such a case. The note says of the series as a whole "best yet," of the first half "uneasy" of the second half "first rate." The figures are: dark 154^σ with mean variation 12^σ, steady light 129^σ with mean variation 8^σ. Records 134–7 also ought to have more weight than the average series. Their note says "best part of the day, excellent physical condition, mind clear and sharp." The figures in this case are: two ears 129^σ M. V. 9^σ, one ear 139^σ M. V. 14^σ. Certainly the average of a dozen series all of which had a similar certificate of the conditions under which they were taken would give different results from those of a set made up from records like 178. The note on this record reads "Not so good; uncomfortable position. Thought distraction very great." The times are: silence 167^σ M.V. 13^σ; metronome 172^σ M.V. 27^σ. To gain the most trustworthy results a large number of experiments should be taken and only those used which are free from all conscious disturbance.

Though introspection is of great value in estimating the general conditions of an experiment and showing the influences which affect the results yet it is not to be trusted in estimating the results themselves. Aside from the fact that the mind is unable to accurately estimate small divisions of time under the most favorable conditions,[1] its judgment is peculiarly liable to be affected by the conditions of the reaction. Its report is what it thinks ought to be rather than what it actually sees. For instance, in series 82–84 the reactor was tired and nervous and therefore judged the reaction-time to be longer than usual. The figures are: one ear 134^σ M.V. 26^σ, two ears 118^σ M. V. 20^σ, showing that the nervous excitement more than counterbalanced the physical fatigue.

In series 150 after having reacted in the muscular way in the previous experiment, the person reacted in the way which he thought would give the shortest time. Accordingly he judged the time of that series to be less than that of the preceding one. The figures for this one are: loud 168^σ M. V. 19^σ, weak 171^σ M.V. 8^σ; for the preceding one: loud 150^σ M.V. 15^σ, weak 156^σ M.V. 31^σ, being just the reverse of his judgment.

---

[1] MARTIUS, *Ueber die musculäre Reaction und die Aufmerksamkeit*, Phil. Stud. 1891 VII 167.

The last four reactions of series 76 were made with a violent jerk. More effort was put forth and the mind inferred that the reaction must be quicker. The average of the last four was 133$^{\sigma}$, that of the first half of the series 132$^{\sigma}$.

Again, in 78 the reaction-time was judged shorter than usual. In this case the hand was raised to the shoulder in every reaction. There was more motion and more effort, therefore the mind judged that the reaction started quicker. The figures are: silence 138$^{\sigma}$ M.V. 13$^{\sigma}$; with fork sounding in the telephone 137$^{\sigma}$ M.V. 28$^{\sigma}$.

In several series, 126a, 126b, 127 the reaction consisted in touching a point on the table six inches from the key. Raising the finger from the key to make this motion broke the spark-coil circuit, and so only the beginning of the motion was registered. Here again the mind was mistaken in judging that the reaction-time was quicker than usual. The average of the parts of these series not subject to other disturbing influences was 141$^{\sigma}$ M.V. 11$^{\sigma}$.

In connection with these experiments where the attention was directed to a motion for which the reaction was a means, the idea suggested itself, but has not yet been carried out, of having a second reaction-key in place of the point on the table. Then we should have recorded in addition to the reaction-time, the time required to make a certain movement. This would doubtless vary from time to time with changing mental and physical conditions. None of its variations could be attributed to influences acting upon the conscious part of the reaction as it would be purely automatic after slight practice. This might throw some light on the relative portion of the variation in reaction-time which is to be assigned to the purely psychical part. Possibly it might be used instead of the simple reaction as a standard for comparing the different kinds of reaction-time.

Between 142 and 143 the reactor went through vigorous muscular exercise so that, whereas 142 was taken with the body in a quiet passive state, during 143 the pulse-beat was strong and rapid, the breathing deep and heavy and the whole system generally excited. The figures for 142 are: 153$^{\sigma}$ M.V. 14$^{\sigma}$ for a loud sound in one ear and 132$^{\sigma}$ M.V. 9$^{\sigma}$ for a weak sound in two ears. The figures for 143, after the exercise, are: 129$^{\sigma}$ M.V. 6$^{\sigma}$ for the loud sound in one ear and 127$^{\sigma}$ M.V. 13$^{\sigma}$ for the weak sound in two ears. The shortening of the time by exercise was 14$^{\sigma}$.

But the chief value of these notes is found in the light which they throw upon the nature of simple reactions. In the first place, are these reactions muscular or sensorial?

Wundt says that, with a signal loud enough to be clearly heard, we naturally react in the muscular way. He explains the difference between the time of reactions to weak sounds and those to loud sounds as due to a passing from the sensorial to the muscular way of reacting. In all of our experiments, with a few exceptions, the signal to react was a loud sound. This would seem to indicate that our reactions were muscular. Furthermore, the two criteria, which Wundt regards as sure signs of muscular reaction, were both present. In six cases at least a reaction was registered just before the signal to react was heard, while scarcely a series passed in which there was not one or more reactions to a warning.

On the other hand, throughout the whole course of experiments the reactor believed that he was reacting in the sensorial way. The attention, with the few exceptions about to be mentioned, was invariably directed to the ear or rather, as it seemed to him, to the sound to be heard. The eyes turned in that direction and there was a distinct feeling of accommodation in that part of the head, due to a combined muscular and nervous excitation. The reactor even went so far as to attempt reactions after the muscular way, carefully directing the attention toward the hand or the movement to be made. In one case, before the reaction habit had been formed, the reaction was shortened in this way from about 140^{σ} to 100^{σ}. In one of the later series, 139, an effort was made to have the last three reactions muscular, two of these were 110^{σ} and 112^{σ} while the average of the other half of the series was 142^{σ} M.V. 8^{σ}. These would seem to be true cases of muscular reaction, if there be such a thing. But in general the attempt to shorten the reaction-time by turning the attention toward the hand or the movement to be made was a decided failure. More often the time was lengthened. It seemed very difficult to overcome the habit of turning the attention toward the ear.

It would seem that those experiments in which the attention was directed to a peculiar movement of the hand or arm, to touching as quickly as possible some point near the key or raising the hand as quickly as possible to the shoulder, satisfied the definition of muscular reaction. Yet none of these show any signs of a decrease in the reaction-time.

Finally, in none of the reactions save those in which there was an attempt at the muscular method, did the person experience that peculiar physical fatigue which is generally ascribed to the muscular mode of reacting. The fatigue was always mental. As such it was very marked at the end of five or six series. From this point of view these reactions must be regarded as sensorial.

But again, according to WUNDT, the peculiar nature of muscular as opposed to sensorial reaction lies in the fact that, while the sensorial reaction contains an apperceptive link in the chain of causes leading to the reaction, this disappears in the muscular method and the reaction becomes a purely automatic brain reflex.

Turning to the notes taken in the reaction-room we read, "Reaction a, 1, series 96, was made in spite of a resolve not to react." This was certainly a purely "automatic brain reflex" and contained no "apperceptive" link. The time of this reaction in the table is 222^{σ}. The average of the rest of the series 197^{σ} M.V. 26^{σ}. Reaction a, 9, series 134, was made while consciousness was entirely absorbed in something else. When it returned to the scene of operations it was quite surprised to find that a stimulus had been received and a reaction made in its absence. Its servants had done better than it expected. Surely this must be an "automatic brain reflex," with no trace of conscious perception or "apperception." The time was 183^{σ}, that of the whole series 124^{σ} M.V. 7^{σ}.

In series 99 one reaction took place before the will to react. That was set down at the time as a brain reflex. Its time however was not materially different from that of the other reactions in the series.

Several times, for instance in 108, it was remarked that a reaction to a weak sound only raised the finger a little whereas the reaction to a loud sound raised it over an inch.

These instances all seem to show that as soon as the habit is formed all our reactions are in the main brain reflexes. But they show just as conclusively that quick reactions are something more. The reflex action left to itself is slow, compared with the reflex action with the concentrated effort of the mind to hurry it along.

WUNDT lays great emphasis upon reactions to the wrong signal as proving the reflex nature of muscular reaction. MARTIUS[1] takes him to task for this and proves that he is wrong by showing that the same phenomenon occurs in sensorial reactions. WUNDT is right. They do prove that muscular reactions are brain reflexes. But they also prove that sensorial reactions are reflex in exactly the same sense. A note was made, referring to 127a, in which there had been a reaction to a warning, "every warning is heard with a tendency to react." And so it is with all sounds. All sounds tend to produce motion in some part of the body. We notice it in the case of loud sounds, in the case of sounds which startle us and especially in the case of rhythmic musical sounds. In the same way reaction is a

[1] See the article cited above.

brain reflex. Therefore the difference between sensorial and muscular reactions is not to be found by deciding whether or not they are brain reflexes.

The key-note to much of the confusion about the different kinds of reaction lies in the indefinite use of the word attention and in a lack of careful introspective analysis of what actually takes place in consciousness.

The word attention is most commonly used in the sense of ideational attention. This kind of attention is described by such expressions as: "Having a clear idea of the object of attention;" "keeping the object in the foreground of consciousness;" "thinking about an object calmly and quietly, yet clearly." It is passive as distinguished from the two following varieties of attention. There is little feeling of effort. What there is, is largely devoted to the inhibition of other ideas. Doubtless there is a slight innervation and muscular contraction but they are not prominent in consciousness.

This kind of attention can be directed to any part of the body, to any motion to be made or stimulus to be perceived, or to something entirely disconnected from the experiment. For instance, in one series, 96, the reactor fixed his attention on a lecture which he had just attended. The time for one ear was 200^{σ} M.V. 27^{σ}, for two ears 179^{σ} M.V. 24^{σ}. This exceptionally long time was not due entirely to voluntary diversion of the attention; the series was also taken without a warning to tell when the signal was to be expected.

As a rule this kind of attention does not shorten reaction-time. So far as distinct thought forms are concerned, the nearer a blank the mind can be kept the more satisfactory seems the reaction.

Often, turning the attention to another object seems to facilitate the movement, just as in writing the hand moves more freely when the attention is directed to the word being written than when it is directed to the muscular effort involved. It seems to drain off the surplus ideational force and leave the field clear for the reaction.

Using the word in this sense MARTIUS is right in criticizing MÜNSTERBERG when he speaks of the idea of the sound as fusing with the idea of a movement to be made. There is no fusing together of these ideas. Association is the word which describes their relation to one another, and the association is always a temporal succession, so far as the ideas themselves are concerned. It is impossible to keep two of these ideas in consciousness for any length of time. When the effort is made, it results in a rapid passing from one to the

other. First one comes into the foreground of consciousness, then the other.

A second sense in which the word is used is that of neural attention. Were it not for the fact that the word usually implies an increase in the muscular tension this might be called innervation. It results in bringing into consciousness the neural sensations. Sometimes it seems like a voluntary control of the nerve-force similar to the involuntary change which is produced by a severe strain when an increase in nervous excitement for the time being counterbalances physical fatigue. Closely combined with it there may be more or less of the feeling of outgoing will force as experienced in willing-games where one person wills another to do some particular thing.

This is closely connected with a third meaning of the word attention, namely, feeling-attention, i. e. the becoming immediately conscious of different parts of the body, which may be expressed either as bringing those parts into consciousness or as extending consciousness into them.

Using the word attention in either of these meanings it is possible to turn the attention to different parts of the body at the same time and to speak of ideas melting together. But the ideas here are quite different from those which we found in the first division.

In one case, 136, this attention was directed to all parts of the body at the same time. It seemed to increase the nerve-force and to result in a general excitement of the whole system. The average time of this series was 148^σ M.V. 17^σ, that of the series just before and just after, under the same conditions was 129^σ M.V. 10^σ. But a single experiment is hardly sufficient to show the effect of this kind of attention. No experiments were taken in which this kind of attention was directed to one or two parts of the body during a whole series.

A fourth sense in which the word attention is used is that of muscular attention. Involuntary changes in the condition of the muscles take place in response to various psychical changes; for example, they become tense in a fit of anger. To a large extent a similar change may be produced by voluntary effort. Something similar to this is usually meant by the expression "innervate the muscles." We can keep the muscles of the hand or arm relaxed or in a state of tension independent of the three kinds of attention already mentioned. Record 100 is an example of this; the first half was taken in the usual way and had a time of 146^σ M.V. 33^σ, the second half was taken with tense muscles and had a time of 120^σ M.V. 16^σ. In

one of the experiments in this series the motor impulse for reaction was not strong enough to overcome the pressure on the key.

A fifth way in which attention can be directed is best expressed as a preparation of the path for the motor impulse from the brain. This consists of a moderate innervation of the whole nerve tract, a small muscular tension and an effort to get a clear idea of the sound and the movement to be made, resulting in a rapid passing of the thought from one to the other. The last experiment of series 113 was made in this way; the time was 127^{σ}, that of the whole half-series 156^{σ} M.V. 15^{σ}.

A sixth state of the attention, one which requires as much effort of a certain kind as any, is that of inattention. All ideational attention, all neural attention and muscular attention are withdrawn leaving the reaction mechanism as far as possible to work automatically. This reduces the circulation, the nervous and muscular tension and with that the whole energy of the system. The tension of the muscles becomes so weak that they sometimes fail to move the very light spring in the reaction-key. By this means many persons are able to put themselves to sleep in a short time. Series 210 was taken in this condition; the time was, in the dark 141^{σ} M.V. 13^{σ} with a steady light in the field of vision 140^{σ} M.V. 8^{σ}.

None of these six descriptions accurately state the condition of the attention in the majority of our experiments. The most prominent feature was always an expectant attention, a strain in the muscles of the ear and a waiting for the sound. There was no attempt to form an idea of what the sound was to be, but simply an effort to hear it as quickly as possible. At the same time there was an under-current of neural and muscular attention directed to the hand and arm. If it is proper to use the terms primary and secondary consciousness, the primary was engaged with the sound, the secondary with the motor apparatus.

Aside from these seven phases of attention numerous other combinations of the three elements are possible. The dividing line between the classes is not a sharp one. All three or any one can be given especial prominence. Certainly the expressions muscular reaction and sensory reaction are of themselves very indefinite and give no accurate descriptions of the distribution of psychic energy.

With these different kinds of attention in mind it would be impossible to agree with JAMES when he says,[1] in speaking of WUNDT's and EXNER's experiments, "The preparation to react consists of

[1] Principles of Psychology, I 438.

nothing but the anticipatory imagination of what the impressions or the reactions are to be" and "It is impossible to read Wundt's and Exner's pages and not to interpret the 'Apperception' and 'Spannung' and other terms as equivalent to imagination." A little practice will enable one to become master of all the different phases of attention here mentioned and many others more difficult to describe.

The remarks thus far have referred to voluntary attention. On the other hand there is a large involuntary element always present in the state of attention at any given time. This changes with practice and with the mental and physical condition. One naturally falls into a habit of reaction. The attention in that case is largely involuntary and resists all efforts of attention in other directions but cooperates with additional voluntary attention in the same direction. When a person is sleepy he has little control over the attention. The same is true when he is wrought up to a high state of nervous excitement.

The mass of bodily feelings varies with changing physical conditions; when one is fresh and vigorous they are large and massive and the motor impulse to reaction seems to meet more or less resistance in passing through them. After prolonged bodily or nervous strain these feelings tend to grow less and their center gradually rises. The extremities drop out of consciousness and the reaction seems to take place with less resistance. The background of all these various forms of attention is the constant play of psychic life. Waves and ripples of feeling and conation are incessantly passing through the mind. More clear cut and easily recognized are the ideas and images of the memory or imagination which follow each other at their own fancy. Now they pass along lightly like fleecy clouds over a summer sky. At the sound of the warning they vanish from consciousness and all the energies of the mind are bent to catch the coming stimulus and make the reaction. At another time the thoughts roll along like heavy irresistible storm-clouds. They heed not the faint warning or even the signal itself. Throughout a whole series the mind will be busily engaged inventing new apparatus, improving the old or struggling with some great problem of life. The reaction, so far as consciousness is concerned, goes on automatically. No amount of effort at the end of the series can call into consciousness a single fact connected with the reaction, nothing save the elements of this dream-like stream of consciousness. But during such a series let there be a break in the regularity in the recurrence of warning or signal and the mind is instantly alert to

inquire into the matter. Though apparently absorbed in other matters, yet there is a kind of unconscious attention being directed to the reaction.

Again, when the mind is apparently wholly engaged in the matter of reacting, an idea will suddenly come into the mind from some mysterious quarter with force enough to carry away for the moment all the attention, unconscious as well as conscious. In series 127 there was such an instance. An idea suddenly flashed upon the mind just as the signal was heard and the motor impulse being started; the whole force of the attention was diverted and the only impulse which reached the hand was a tremor too weak to raise the finger.

These observations and others suggested by the summary of the notes taken during the course of the experiments show that there is still much which can be learned about the mind and its processes from the study of reaction-time. They suggest a large number of experiments which might be carried out along the different lines of attention. Most of all they emphasize the great value of introspection. For the rougher work in reaction-time this may not be necessary. We can easily detect differences in reaction-time due to the presence of very distracting influences, to the effect of practice, to changes in intensity of the stimulus, to a change in the quality of the stimulus, and to many similar changes. But as soon as we inquire into the nature of reaction, and try to make quantitative estimates of these changes and to learn more about the nature of the mind's activities, then introspection is necessary.

Some will criticise these reaction-experiments because they were all made upon one person, and therefore can give no idea of what would be the result in another case. They say that results to be of value must be made upon a great many persons and the average computed as has been done in the case of physical measurements.

In reply it may be said of physical measurements that while statistical results from one point of view are of great value yet all the important discoveries in physiology have been made upon individuals. Statistics would never have discovered the circulation of the blood or the constituent parts of the brain. The human body is for the most part the same the world over and a discovery in anatomy in one body holds good in all others. The same thing is true in psychology. Nearly all the results thus far obtained have been gained from the study of individuals. The human mind like the human body is for the most part the same in its workings everywhere and

a discovery in one mind will hold good for other minds. Though important results will be reached along statistical lines yet the greatest advance in the future as in the past will in all probability be made by discoveries in investigating individuals.

EXPERIMENTS SHOWING THE EFFECT OF CHANGES IN THE STATE OF ATTENTION UPON THE MAXIMUM RATE OF VOLUNTARY MOVEMENT.

In a series of experiments carried on at Clark University, DRESSLAR found that the time required to make 300 taps varies with different individuals and with a change in the mental and physical condition of the same individual. Increased central activity favored an increase in the rate of voluntary movement.[1] BRYAN continuing the investigations upon a large number of school children found that the rate of tapping for the different joints of the hand and arm varied with children of different ages in accordance with their physical and mental development.[2] Many interesting points were brought out as to the effect of fatigue and the relative development of the different joints. But with the apparatus which they used it was impossible to show the relation between the individual taps of the series. The most that could be done in that line was to detect a slight decrease in rapidity due to fatigue when more than 300 taps were taken at a time. Otherwise it was taken for granted that the rate was uniform throughout the series.

The following experiments were taken with the purpose of investigating this question of the uniformity of rate. Our reaction-time apparatus offered the best possible means for measuring the interval between each successive tap. The taps were made upon the reaction-key in the dark room, and recorded by the electric sparks on the smoked paper of the drum. About 300 taps could be recorded on one paper by turning the drum slowly. An electro-magnetic time-marker was placed beside the tuning-fork and connected with a pendulum which beat seconds. This enabled one to tell at a glance the number of taps in a second in any part of the curve while, without it, it was necessary, in order to find the number of taps in a second, to add up the successive intervals, given in thousandths of a second, until they amounted to a second, and so on throughout the series.

---

[1] *Some influences which affect the rapidity of voluntary movements*, Am. Jour. Psych., 1891 IV 514.

[2] *On the development of voluntary motor ability*, Am. Jour. Psych., 1893 V 1.

As a matter of fact this longer process was gone through in the preparation of the curves described below because there was a slight irregularity in the successive spaces marked off by the pendulum, due to the fact that the mercury contact was not made exactly in the middle of the arc of oscillation.

A click on the bell was the signal to begin tapping and the instructions were to tap as rapidly as possible until a second click announced that the record was complete.

TABLE VIII.

No.	A	MV	MV′	No.	A	MV	MV′
1	139	15	12	11	139	11	9
2	134	9	9	12	144	11	8
3	135	7	7	13	147	14	8
4	130	7	6	14	147	14	7
5	130	4	4	15	138	7	6
6	133	6	7	16	143	9	5
7	130	9	7	17	114	15	6
8	133	4	4	18	148	19	5
9	138	6	3	19	143	16	5
10	138	6	4	20	139	10	5

No., number of group.
A, average time.

Table VIII gives a summary of the figures for one experiment. There were 180 taps, or rather intervals between successive taps, recorded in this experiment. They were collected into groups of nine for the purpose of showing the gradual changes in the rate during the series; instead of finding that the intervals are all the

same, we found a continual variation. During the 180 taps there were only four cases where successive intervals were recorded as the same. The intervals were collected into groups of nine for the purpose of showing the gradual changes in the rate during the series; only the averages of these successive groups are given in the table. The deviation of the individual intervals was computed in two ways. The first deviation-column represents the average deviation of each

TABLE IX.

Name	Date	A	MV	T	S
W. I. C.	Feb. 25.	133	9.3	7.5	39.9
"	Feb. 28.	147	9.5	6.8	44.1
"	"	145	9.	6.9	43.5
"	"	147	10.	6.9	44.1
"	"	138	9.	7.2	49.4
Average		142	9.3	7.1	44.2
C. B. B.	Mar. 24.	175	11.	5.7	52.5
Dresslar		117		8.5	35.3
"	Av. of 20 visitors	167		6.0	50.4

A, average time.
T, number of taps per second.
S, number of seconds for 300 taps.

interval of the group from the total average of the 180 intervals. The second column represents its deviation from the average of its own group of nine. The difference between the two is due to the gradual change in rate. Looking at the first column one would say that the irregularity of tapping increased very fast toward the end of the series but a glance at the second column shows that this was not the case. On the contrary there is a steady increase in the regularity of the intervals in the different groups but, owing to the

rapid increase in the intervals themselves, the deviation of the later groups from the total average is greater than that of the earlier ones.

Six of these experiments or sets of taps, were taken and they all show the same general results. The average for the successive groups of nine taps for the six experiments were 140^σ, 137^σ, 136^σ, 134^σ, 139^σ, 144^σ, 146^σ, 147^σ, 148^σ, 150^σ, 145^σ, 150^σ, 150^σ, 154^σ, 154^σ, 154^σ, 153^σ, 152^σ and 150^σ. These averages show an increase in the rapidity of tapping for the first four groups of nine. After that there is a gradual falling off for five groups then a slight recovery during two groups followed by a still greater slowing up for four groups and then another slight recovery. The average of the first set of groups is 140^σ, that of the nineteenth, which is the last to contain records from all the six experiments, is 150^σ.

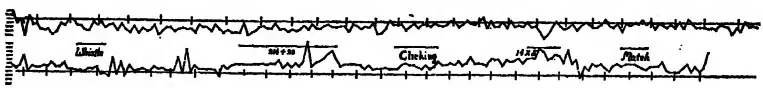


Fig. 14.

Table IX contains the final averages of the six experiments. Besides the average interval between successive taps, and the average deviation from it, the number of taps per second has been computed, and also the time required to make 300 taps. This was done for the purpose of comparing the results with those obtained by DRESSLAR and BRYAN. The time required for 300 taps is naturally somewhat less than it would have been if that number of taps had actually been made; for the experiments show that the last taps of a series are much slower than the first owing to fatigue.

However, we are not so much concerned with the number of taps in a series as with the regularity of the intervals between the successive taps. This can be studied much more satisfactorily by means of graphic representation than by tables. Accordingly the records of two series have been plotted. The resulting curves are given in fig. 14.

The curves represent the intervals between the successive taps of each series. The abscissas show the place of each tap in the series while the ordinates represent the length of the interval between two adjacent taps, each vertical division on the paper representing 10^σ and the horizontal line being taken to represent 150^σ. Thus the high parts of the curve correspond to slow and the low parts to rapid rates of tapping. The short vertical lines mark off the seconds.

A glance at these curves shows how the interval between the taps is constantly varying. Only in a very few instances does it remain the same for two successive intervals. For two, three or even four successive taps there will be a gradual increase in the rate until the mind is satisfied with its work or until it is unable to keep up this high strain of attention, when the rate again falls off. This effect can be seen in the second and third seconds of the first curve. Again as in the fourth and fifth seconds of this same series the process of change is more rapid. The rate alternately rises and falls with each successive tap. In the sixth second the rate falls off for three intervals, gains in the next what was lost in the last two, and again loses the same in the two following. Most of these changes pass unnoticed by the person while he is tapping. He is, however, at times conscious of a falling off in the concentration of attention and tries to correct it by a special effort.

The second curve, corresponding to the record of C. B. B. in table IX, is almost entirely above the 150^{σ} line, showing a slower rate of tapping than the other experiments. The explanation of this is the fact that the experimenter had learned of the great irregularity of the intervals and in this case aimed to tap as regularly as possible rather than as fast as possible. The result shows a slower rate but also the same irregularity, the same increase and falling off in the rate, now rapid, now gradual.

In all of these records aside from the usual variation in rate there are a few unusually long or short intervals. In the nature of the case there are more long ones than short ones. In one case there seems to have been a momentary break in the series, due very likely to a condition sometimes experienced by other persons in similar experiments. All of a sudden in the midst of a series of taps the arm seems to be momentarily paralyzed.

Over and above this variation in the rate from one tap to another there are larger gradual changes from second to second. During the first second there is always a general increase in the rate. After the middle of each curve there is a gradual slowing up. Dresslar detected signs of fatigue after 300 taps. My experiments show a decrease in the rate soon after 100 taps.

But aside from these two changes in the rate, an alternate increase and decrease of the successive intervals and a gradual slowing up toward the end, there is a third change brought out by these curves, which is of great interest. If we turn the curves around and look at them from the end so that the line of vision makes a small angle with

the plane of the paper we notice a gradual rise and fall of the curve every two or three seconds. This is doubtless due to the gradual rise and fall of the attention and corresponds to the alternate appearance and disappearance in consciousness of a sound just loud enough to be heard, as for example the ticking of a watch held at just the right distance, and with the alternate appearance and disappearance of faint rings on a rapidly rotating disk.[1] The chief point of difference is that in those cases the phenomenon is a matter of consciousness whereas in this case the person is entirely unconscious of the rise and fall in the rate. This fact shows that the rise and fall are not confined to ideational attention but are also characteristic of the subconscious muscular attention. These results agree with those recently obtained in the field of sight and hearing[2] in not showing any regular period of rise and fall. In general it occurs every three or four seconds.

In the second, third, fourth and fifth experiments an effort was made to distract the attention of the person tapping. The warning and signal used in reaction-experiments were sounded several times and the tuning-fork sound described in one of the experiments in reaction-time was turned on while the ear was at the telephone. In some cases there may have been slight changes in the rate of tapping owing to their influence, but that was by no means clear. In fact such weak sounds would hardly be expected to produce much disturbance in such heavy work.

In the sixth series the distractions were greater and show themselves plainly in the second curve. They were produced by an assistant in the reaction-room. A second electro-magnetic marker was placed on the drum and connected with another key in the reaction-room; by means of this key the assistant could register by the side of the time curve the beginning and the end of each disturbance.

The nature and place of the disturbances are noted just above the curve; their duration is indicated by the length of the short lines above the curves. In every case it will be seen that the disturbance produced marked changes in the rate. The blowing of a loud whistle was followed by a great irregularity. The mental addition of 214 and 23 at first made the rate very regular, more so than at any other point in all the series. This was during the period

[1] Lange, *Beiträge zur Theorie der sinnlichen Aufmerksamkeit und der activen Apperception*, Phil. Stud. 1888 IV 390.

[2] Marbe, *Die Schwankungen der Gesichtsempfindungen*, Phil. Stud. 1892 VIII 614.

between hearing the problem and beginning to solve it. At first the person was reluctant to undertake the problem. He felt that all his energies should be directed to the tapping but finally realizing that the problem must be solved he went at it. The first attempt at solution produced marked irregularly and real work was accompanied by a steady falling off in the rate. As soon as the answer was reached the attention returned to the tapping and the rate rapidly recovered.

A clicking with the tongue, such as is used to make a horse go faster, owing to this association seemed accompanied by irresistible impulse on the part of the person tapping to accelerate his movements. There was a slight falling off in the rate at the first surprise and then a gradual increase for four taps. But to the great surprise of the person who did the tapping, the rate did not exceed that which had been maintained since the last disturbance. The mental multiplication of 14 by 5 produced great irregularity as well as a general decrease of the rate. The sight of a lighted match, however, produced great regularity and a steady increase in the rate.

This sudden increase in the regularity of tapping without a marked change in the rate, when the attention is attracted by some other object, is similar to the fact noticed in some of the experiments in reaction-time, namely, that more regular results were sometimes obtained when the mind was partially absorbed in other things. The more superficial, ideational attention is directed to them while the unconscious muscular attention which is largely a matter of habit runs along more smoothly and automatically. As the mind is absorbed in the secondary problem, the more substantial subconscious attention gradually withdraws from the muscular effort and reinforces the mental effort.

On the other hand, as was also shown in the reaction experiments, some sudden surprise, in this case a clicking sound or a lighted match, at once draws away the deeper as well as the more superficial attention. But as soon as the surprise is over there is no strong intellectual effort required to watch the light and the subconscious attention returns unhindered to its habitual task, while the more fickle ideational attention remains captivated by the new sensation.

There can be no question that these last changes in the rate of tapping are due to disturbances of the attention. There can also be no question that the second change mentioned, namely the gradual slowing up after the first ten seconds, is due to fatigue. This

fatigue may be psychical, muscular or neural. Judging from the results obtained by LOMBARD in his investigation of the amount of work which can be done by a person under different conditions,[1] it is probable that the fatigue is in the nerve centres.

In the case of the change first described, namely the variation from tap to tap, the cause is not so evident. The fact that a partial withdrawal of the attention stops it and makes the intervals regular indicates a psychical cause. Under the additional strain of conscious voluntary attention the nerve mechanism acts more irregularly. Irregularity seems to be a characteristic of the higher forms of psychic life. The usual explanation is that there are two sets of nerve centres involved, the higher more unstable brain-centres and the lower more automatic ones of the smaller brain and spinal cord. A disturbance of the attention is supposed to cut off the higher centres from the circuit engaged in the muscular action. Yet both in the tapping and the reacting it was seen that further central activity was accompanied by further decline in the muscular rate. Therefore it seems proper to speak of a subconscious attention in this connection.

The explanation of the third change in the rate, namely the gradual rise and fall, is still more uncertain. Many persons will object to the use of the word attention in this connection. They would claim that it is a purely muscular phenomenon and regard it as supporting MÜNSTERBERG's explanation of the appearance and disappearance of faint visual images. The disappearance, he thinks, is due to fatigue of the muscles of the eye. As soon as the image disappears they relax and begin to recover; when they have regained their strength the object comes into consciousness again.[2]

It seems certain that this rise and fall in the rate must be closely connected with the appearance and disappearance in consciousness of faint sensations but it seems equally certain that they are not due to muscular fatigue. In the first place, it must be remembered that this rapid tapping is not a mere muscular operation; we have seen that the rate changes with changing psychic states. In the second place, there is no chance for the muscles to recover while the tapping continues. In the case of the eye there is a possibility that the muscles relax when the image disappears. Not so here. In the third place, the real fatigue shows itself in the general slowing up of the rate.

[1] *Some of the influences which affect the power of voluntary muscular contractions*, Jour. Physiol. 1892 XIII Pts. 1 and 2.

[2] MÜNSTERBERG, *Beiträge zur experimentellen Psychologie* 1889 II 69.

Conclusions from the introspective observations.

1. Reaction-time is constantly affected by irregular disturbances a large part of which may be detected by introspection.
2. Introspection is not to be trusted in estimating results.
3. Exercise shortens reaction-time.
4. Reactions to the wrong signal, reactions before the signal is heard and the reflex nature of reactions are not sufficient criteria to distinguish muscular from sensorial reactions.
5. There are at least six distinct kinds of voluntary attention; ideational attention, neural attention, feeling attention, muscular attention, preparatory attention and inattention.
6. The involuntary attention is constantly changing.

Experiments showing the influence of disturbances of the attention upon the voluntary control of muscles.

There have been various devices invented to show the effect upon the body of various psychical disturbances. Some of the effects which have been pointed out are a rise in the temperature of the brain, a change in the circulation, a contraction of involuntary muscles, increased activity in the various glands, and a change in the force with which the muscles can be contracted. Lombard found that the knee-jerk showed marked changes in the case of mental disturbances. We have seen that the reaction-time and rate of tapping are influenced in a similar way. Jastrow[1] describes a piece of apparatus which he calls the automatograph, constructed for the purpose of registering involuntary movements of the hand. The hand is placed on a freely moving table to which there is attached a marker that records every movement upon a smoked paper. It was found that when the apparatus is screened from the eyes of the person experimented upon that the hand involuntarily follows in the direction toward which the attention is turned.

During the course of my experiments Dr. Scripture suggested that the accuracy with which a person could steadily point to a given spot would be a measure of the amount of attention he could direct toward the work. In accordance with that suggestion the apparatus shown in fig. 15 was arranged to measure this accuracy. It differed fundamentally from Jastrow's automatograph. In his case

---

[1] Jastrow, *Studies from the University of Wisconsin*, Am. Jour. Psych. 1891 IV 398; 1892 V 223.

the pointer was concealed from the person performing the experiment; here the pointer was in full view and every effort was made to keep it steadily opposite a given mark.

A receiving tambour was fixed to a standard in a horizontal position, face upward, so that the lever moved in a vertical plane. A light pointer eight inches long was attached to the lever. Back of the tip of this pointer a piece of card-board was fixed in a vertical position parallel to the plane of the lever. A dot was made on this card-board just below the end of the pointer. The recording tambour was adjusted to register the movements of this lever upon the smoked paper on the drum. An electro-magnetic time-marker was placed by the side of the recording tambour and connected with a pendulum which beat seconds.

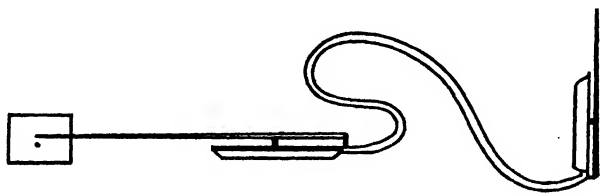


Fig. 15.

This apparatus having been arranged in a convenient position, a person placed his finger on the lever of the receiving tambour and, with the whole arm free, kept the end of the pointer as steadily as possible opposite the dot on the paper. It was found impossible to keep the point exactly opposite the dot; there was a constant vibration above and below. Within certain limits the movements of the point increased or decreased inversely with the amount of attention given to the work.

Figs. 16–19 contain sections cut from the record of one of these experiments. The upper curve was drawn by the lever of the registering tambour and shows the vertical movement of the finger. The heavy broken line was made by the time-marker and each section represents one second. The fact that some are longer than others shows that the drum was not turned with uniform speed; this fact must be kept in mind while examining the records.

The irregular shape of the curve shows the constant movement of the finger. In the centre of each of these sections there is a still greater irregularity. These disturbances all correspond to disturbances of the attention at the time the record was made.

A mark shows the point where the disturbance began, the white mark toward the right marks the point where the disturbance ceased.

Fig. 16.

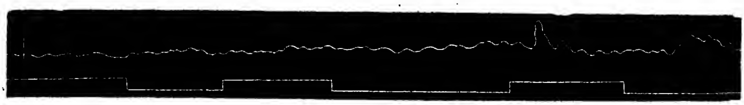


Fig. 17.

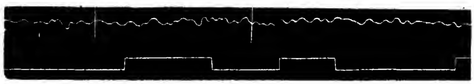


Fig. 18.

Fig. 19.

Fig. 16 shows the effect of an accidental distraction. There is great irregularity just at the time when another person happened to leave the room. The first half of fig. 17 indicates the effect of a sound which originated in another room. The distraction seemed to steady the hand; great irregularity occurs about the time of return of attention. Fig. 18 shows the effect of the mental subtraction of 88 from 89. In this case the problem was so simple that the answer was given immediately, yet the disturbance is very marked. In fig. 19 the attention was drawn away from the work in hand by a person walking around the room.

These are only a few of the instances in this one experiment which show the inability of the mind to resist the smallest influences even when the will is set resolutely against them. It seems that in cases where the attention is distracted in a way such as to cause a tendency to move the eyes or when mental work is being done, the control of the muscles is uncertain. When the disturbance is a slight one, such as noticing a noise in another room, the distraction seems to aid the regularity. This latter case seems to be analogous to the well-known fact that we can perform numerous actions much better when only half attending to them.

ON MONOCULAR ACCOMMODATION-TIME

BY

C. E. Seashore.

Though the limits of accommodation and related problems have received due attention from Helmholtz and others, the *time* of changing the focus of the eye has hitherto been scarce investigated. Volkmann[1] seems to have been the first to experiment upon the subject. By applying Scheiner's experiment he found that he could change the accommodation of his practiced left eye 29 times from 11 in. to 6 in. and back in half a minute. Vierordt[2] devoted a special treatise to the subject in 1857 and Aeby[3] later examined the duration of the act of accommodation within the limits of 315^{mm}. The latest and only important investigation on the subject that has come to the writer's notice is a series of experiments by Barrett.[4] It will be referred to and compared with the present study from which it differs both as to method and results. The success of these experiments in Yale Psychological Laboratory is due to the efficient advice of Dr. E. W. Scripture, under whose supervision they have been conducted.

The problem I have undertaken is, to determine the time required to change the accommodation of the eye in either direction between two given points. As the object was the establishment of fundamental laws and not the collection of statistical material, this research is limited to observations on the right eye of persons with a normal eyesight accommodating for points in the direct line of vision under the most favorable circumstances. The psychological method of differential reaction-time has been used because it is apparently impossible to determine the accommodation-time by any direct physiological methods.

---

[1] *Sehen*, Wagner's Handwörterbuch d. Physiol. 1850 III 1. Abth. 309.

[2] *Versuche über die Zeitverhältnisse des Accommodationsvorganges im Auge*, Arch. f. physiol. Heilkunde, n. F., 1857 I 17.

[3] *Die Accommodationsgeschwindigkeit d. menschlichen Auges*, Zt. f. rat. Med., III. Reihe, 1861 XI 300.

[4] *The velocity of accommodation*, Journ. of Physiol. 1885 VI 46.

APPARATUS.

The variables are: (1) the distance of the nearer point, (2) the distance of the further point, (3) the direction of accommodation, i. e. whether the focus is to be changed from near to far or *vice versa.*

The solution of the problem required (1) an apparatus that holds the nearer point in view and suddenly exposes a point further off, (2) one that holds the further point in view and suddenly exposes the nearer point, (3) an arrangement to mark the instant the second point comes in view, (4) a reaction-key, (5) an apparatus for recording the time.

In the first experiments I used a revolving disc having holes near the edge through which the further point could be seen. The nearer point was indicated by objects on the disc at points alternating with the holes. The disc was arranged with weights, pulleys, springs and levers so that in its revolving it could be stopped to expose the nearer and the further point alternately. The person experimented upon was required to look through a tube extending from the eye nearly to the disc. One electric wire was connected with an isolated copper brush which made contact with the disc at the moment the second point could be seen. The brush was at all other points isolated from the metal plate by a cardboard covering. The other wire was connected with the disc and went through a closed-circuit reaction-key. Both wires were then run to the chronograph-room where they completed the circuit through an electromagnetic time-marker. Two markers were used on the drum. One registered the vibrations of the tuning-fork; the other, running parallel to it, indicated the make and break of the current from the experiment room. To compare the two lines of the record perpendiculars were dropped from one line to the other at the points of make and break of the current.

After the first and second sets of experiments I used another apparatus which served the purpose better. With that I also used a simpler and more accurate method of recording. This latter apparatus consisted of a Laverne pneumatic camera-shutter to which electrical connections were added. There were two arrangements of the slide and the electric connections: (1) to drop the slide and expose the nearer point, (2) to raise the slide and expose further point. In the first arrangement one end of the electric wire was connected with the metallic body of the shutter. The other end was fastened to a binding-post which was connected (1) with a wire

spring which made contact with a projecting spring-arm on the slide at the moment the further point was cut off from view and the nearer point exposed, and (2) with a metal plate on which the projecting arm rested and made permanent contact when the slide came down. Both the contact-point and the metal plate were isolated from the metallic body of the shutter. In the second arrangement the slide was made to fly up and stop against a special catch. When the slide flew up its projecting arm struck the special contact spring at the moment the nearer point was removed from view and the further point was exposed. The special catch against which the slide finally rested at the top, and with which it made permanent contact was connected with the same binding post as the metal plate in the other arrangement. The current went through a closed-circuit reaction-key by means of which it could be interrupted. The current was made for an instant when the slide arm struck the special contact spring, permanently made by the slide arm resting on the metal plate or the special catch, and again interrupted by the reaction-key. The time required was that indicated between the first closing of the current and the breaking by the reaction-key. Heavy wires led from the shutter and the key to the chronograph-room where the circuit was completed.

In taking all except the first two sets of records I used the spark-coil method invented in this laboratory. For a full description of apparatus and method see the article by Bliss on p. 7–10. I did not, however, use the multiple-key described there but led the current directly to the research-room. A 100 v. d. tuning-fork was used but the drum was turned with such rapidity that the waves were sufficiently long to be easily estimated in tenths without error, thus giving me a direct record in thousandths of a second.

The nearer point was represented by a small capital o with a height of 0.7^{mm} and the further point by a large capital O with a height of 25^{mm}, except at the point represented as at infinite distance when a larger object had to be used. This object was a section in the crown of a distant chimney. The letter at the near point was on the slide. The other letter was on a card in a movable support.

The course of the investigation was somewhat in the following manner. First, the nearer point was kept constant at 20^{cm}, and the further points made respectively 50^{cm}, 1^{m}, 2^{m}, 4^{m}, 8^{m}, 12^{m}, and infinite distance. A point over 100^{m} away was considered the same as a point infinitely distant. Then the further point was kept constant

at infinite distance and the nearer point was made successively, 20^{cm}, 50^{cm}, 1^{m}, and 2^{m}. On these ten distances observations were made in accommodating the eye (1) from near to far and (2) from far to near. Both points lay in the line of direct vision. In this line was a tube extending from the front of the cornea in the eye of the subject to within a short distance of the nearer object. The tubes were adjusted at a sufficient distance from the slide to allow light to fall upon the nearer object. There was a special tube for each near distance. The 20^{cm} and 50^{cm} tubes had a bore of 2^{cm}. The 1^{m} and 2^{m} tubes had a bore of 4^{cm}.

Person experimented on.

These results aim to be the records of a typical case. I selected a subject who could well represent the average and gave him the most favorable circumstances, i. e. a comfortable position, good light, medium temperature and avoidance of anything that would distract attention. The results thus have uniformity and comparative value because they are taken on the same person and, as nearly as possible, under similar circumstances. The subject was an exceptionally critical and reliable observer—a fact of considerable importance where we have to trust to his judgment and faithfulness for the attainment of our results.

This series of observations was made on Mr. August Nelson, aged 29, a graduate student of philosophy. His eye is emmetropic with near-point 15^{cm} and far-point ∞; volitional ability, as exercised in concentrating attention, excellent. Reacting over 4000 times to the same stimulus he acquired considerable practice. Practice may have shortened his reaction-time slightly in the later experiments, but the variation was not great as he had made nearly a thousand reactions before I took the records upon which this article is based. Of other subjects reacting to the same stimulus, some take a longer and others a shorter time than N.; his records can be considered as representative of the average man.

Precautions and variations.

Reaction to a visual stimulus is a very complex act. It involves sensation, judgment, determination and other factors. In order to make the act as simple as possible precautions were taken to avoid intricacies and to facilitate perception. Thus, to avoid long and irregular time for discrimination and decision, the plain letter O was selected as the object for which to accommodate. The subject knew just what to expect and where to look for it.

The criticism was made during the investigation that it took time for the second object to "clear up." It was "blurred" at first and "gradually" became clear. That is just the point here investigated, viz: the time required to change the focus of the eye so as to make a clear image. The subject was instructed to use his best judgment and react when the object became clear to him.

Much of the mean variation in time on any one distance we may ascribe to the fluctuation of attention. Its effect upon reaction-time is to be considered as established. In this case I think attention was the great factor in determining the fluctuations around the mean time of "clearing up."

As a constant source of error I would mention the time that it took the slide to move a distance corresponding to the size of the letter at the nearer point. This time was less than 2^σ. Hence the uncertainty as to the time when one letter went out of view and the other was exposed cannot exceed $\pm 1^\sigma$.

Considering all the other objective sources of error, such as direction and strength of light, jarring of the apparatus and disturbances in the room, I would estimate that all the variations due to these do not exceed $\pm 5^\sigma$. The total limit of error was thus within $\pm 6^\sigma$. No uncorrected sources of error could be detected. In the earlier experiments where the unit of measurement was .01 sec. the latent time of the Deprez time-marker was quite negligible; in the later experiments with a unit of 1^σ, the latent time of the electric spark was far beyond negligibility, as was proved by experiments described in the article referred to above.

Method of experimenting.

The person experimented on was seated erect with the right eye before the tube. The left eye was closed but free to move. The reactions were made with the second finger of the right hand. The instructions were: "Look sharply at the first O until the second O is exposed; when you see the second O clearly, react."

The time of the operation indicated on the drum included the time of changing the condition of the accommodation plus the time of reacting to a given stimulus. To get the simple reaction-time I proceeded as above except that the subject was required to focus for the second object only, or on the place where it was supposed to be, and, without any change of accommodation to react every time he saw the same object again. To get the accommodation-time, i. e. the time of changing the adjustment of the eye between two focal

points, I subtracted the simple reaction-time. The records of the reactions were taken in sets of ten to twenty in each; hence, under similar circumstances. The first object was exposed about two seconds before the change and there was an interval of about ten seconds between each successive observation.

I added all the records on each distance in a set and took the average. The tables give these final averages with the mean variation and number of experiments corresponding to each.

Results.

In the following tables I use these abbreviations: *N*, nearer point; *F*, further point; ∞, practically infinite distance; *F* ⟶ *N*, from far to near; *N* ⟶ *F*, from near to far; *n*, number of experiments of which the average is taken; *A*, accommodation-time; *R*, reaction-time; *AR*, accommodation-time plus reaction-time; *MV*, mean variation.

TABLE I.

(Curve I) *N* ⟶ *F*. $N=20^{cm}$. Unit of measurement, .01 sec.

F	*AR*	*MV*	*n*	*R*	*MV*	*n*	*A*
50^{cm}	27.2	7.4	39	26.5	3.8	18	0.7
1^{m}	28.4	3.1	40	26.5	4.4	16	1.9
2^{m}	34.8	4.4	37	32.2	3.7	13	2.6
4^{m}	36.1	2.6	31	32.3	4.0	19	3.8
8^{m}	40.9	7.6	37	35.5	6.3	20	5.4
12^{m}	41.4	11.2	40	31.9	5.7	20	9 5
∞	40.9	5.9	40	31.5	4.5	20	9.4

The figures in tables I and II express hundredths of a second, the last figure being simply the decimal obtained in averaging a column. All the other records are in thousandths of a second. For the sake of comparison and uniformity the first two curves are also marked

in thousandths of a second but it must be remembered that they are based upon the figures in the first two tables.

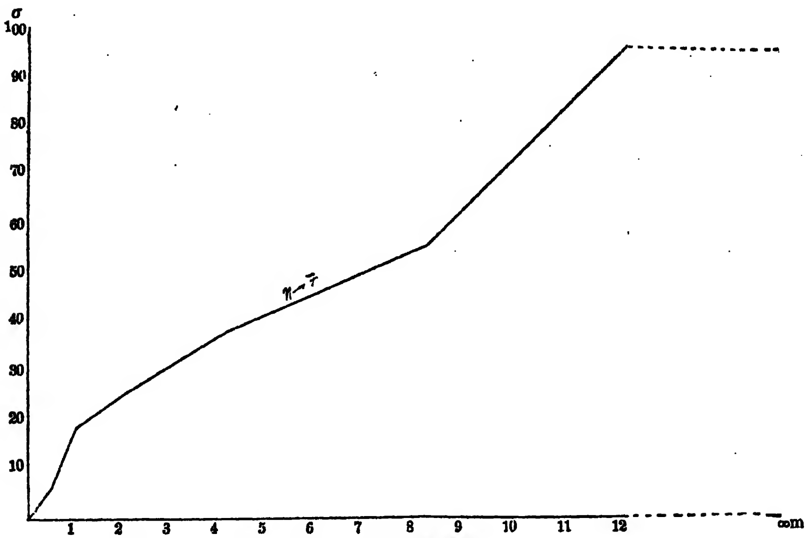


Fig. 20. Curve I.

This table shows that when N is constant, the time of changing the accommodation of the eye from N to F increases with the dis-

TABLE II.

(Curve II) N - - ---> F. $F=\infty$. Unit of measurement, .01 sec.

N	AR	MV	n	R	MV	n	A
20cm	40.9	5.9	40	31.5	4.5	20	9.4
50cm	40.0	7.5	40	34.7	5.6	20	5.3
1m	32.5	4.7	35	27.2	3.5	18	5.3
2m	39.8	7.8	40	35.5	5.4	20	4.3

tance of F up to 12m. Beyond 12m the time of monocular accommodation does not vary because the rays are practically parallel for all such distances. It will be observed that in proportion to the distance of F the greatest change in time is when F is near N, and

that the ratio diminishes to infinity as the distance between the two points is increased.

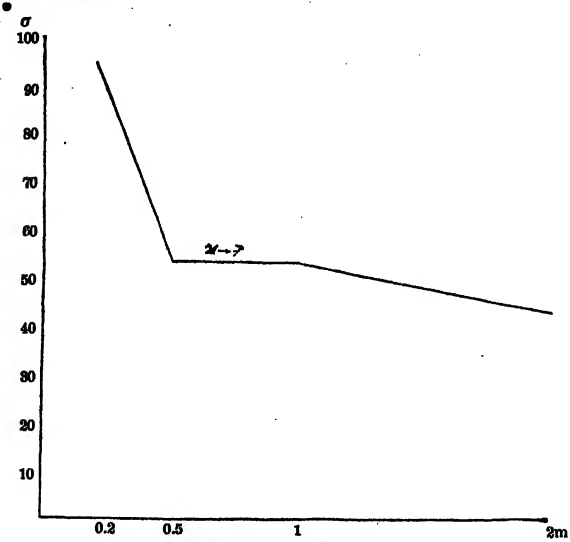


Fig. 21. Curve II.

When F is constant the time increases inversely with the distance of N from the eye up to 2^m or more. The greatest change in time

TABLE III.

(Curve III) $F \longrightarrow N$. $N = 20^{cm}$. Unit of measurement, $\sigma = .001$ sec.

F	*AR*	*MV*	*n*	*R*	*MV*	*n*	*A*
50^{cm}	169	24	40	159	30	18	10
1^{m}	168	22	40	165	21	19	3
2^{m}	178	18	40	157	12	18	21
4^{m}	185	33	40	163	15	17	22
8^{m}	189	27	34	166	19	12	23
12^{m}	213	37	37	152	19	10	61
∞	250	29	34	206	19	20	44

is when N is near the eye. The law of relative variation is the same as in table I, i. e. within certain limits the accommodation-time varies with the distance between N and F, though this variation is not in proportion to the distance.

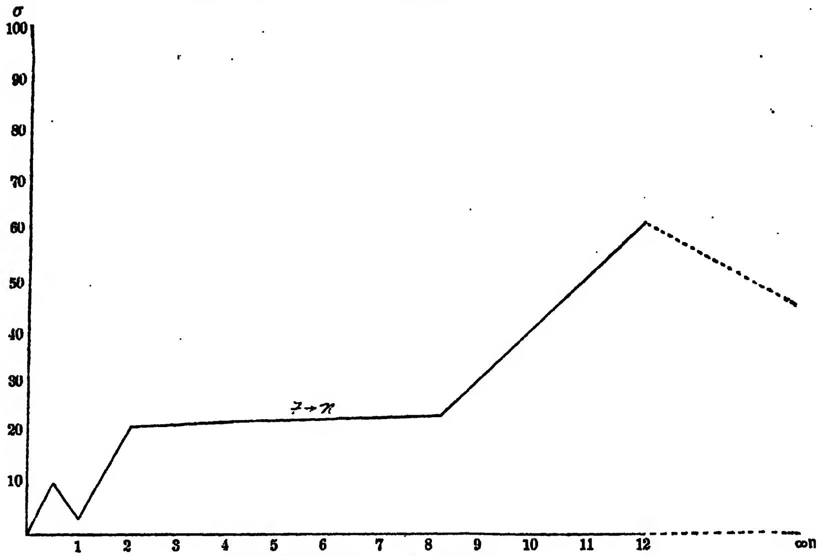


Fig. 22. Curve III.

The same general law is brought out here as in table I; but in this case (F ——> N) the time is shorter and the mean variation is

TABLE IV.

(Curve IV) F - - —> N. $F = \infty$. Unit of measurement, $\sigma = .001$ sec.

N	AR	MV	n	R	MV	n	A
20^{cm}	250	29	36	206	19	20	44
50^{cm}	267	51	33	203	16	19	64
1^{m}	214	19	40	178	17	20	36
2^{m}	205	18	40	162	15	16	43

less than in the other (N ——> F). From a comparison of AR and R in this table it becomes evident that the deviation in the case

of the last figure is wholly due to an exceptionally long reaction-time.

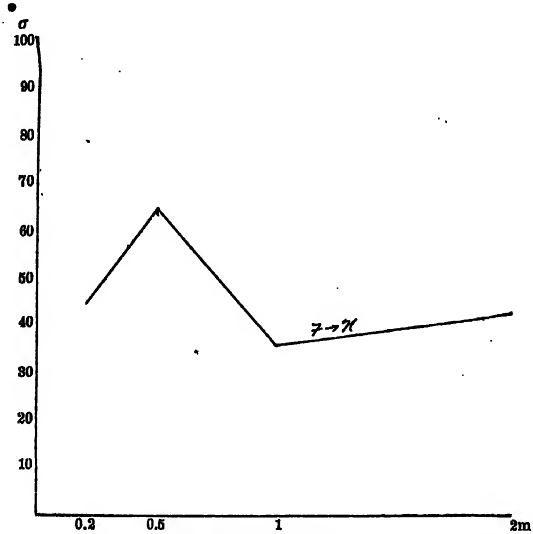


Fig. 23. Curve IV.

This is complementary to table III, and corroborates the same principles for the case where the nearer point is constant.

TABLE V.

(Curve V) *AR* taken $F \longrightarrow N$ and $N \longrightarrow F$ alternately. $N = 20^{cm}$. Unit of measurement, $\sigma = .001$ sec.

F	*a* $F \longrightarrow N$	*MV*	*n*	*b* $N \longrightarrow F$	*MV*	*n*	*b—a*
1^m	174	18	40	183	13	28	9
2^m	184	37	39	220	18	36	36
4^m	211	35	38	229	22	38	18
8^m	269	44	38	297	71	35	28
12^m	335	65	34	398	105	29	63
∞	243	65	40	363	102	40	120

The purpose of this set of experiments is to adduce further proof for the facts brought out in tables I and III, and to show how the

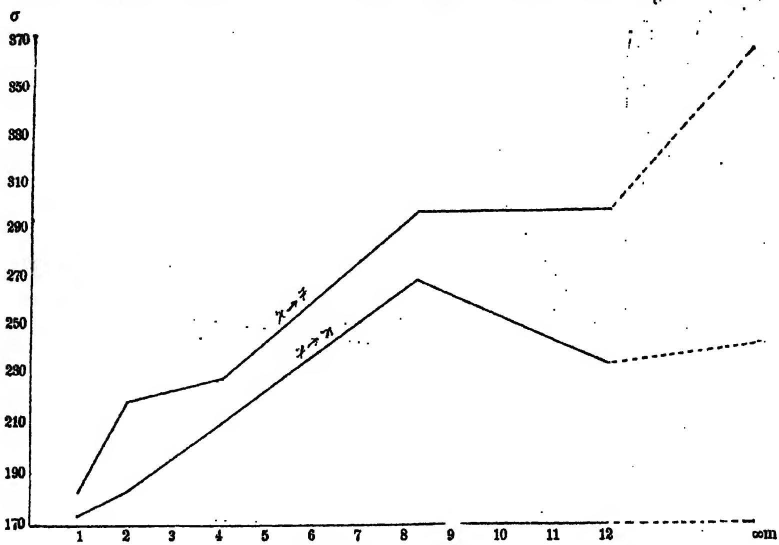


Fig. 24. Curve V.

time is influenced by the direction of accommodation. This table is a comparison of AR taken in series of 20 in each direction alternately.

TABLE VI.

(Curve VI) AR taken $F \longrightarrow N$ and $N \longrightarrow F$ alternately. $F=\infty$. Unit of measurement, $\sigma = .001$ sec.

N	a $F \longrightarrow N$	MV	n	b $N \longrightarrow F$	MV	n	$b-a$
20cm	243	65	40	263	102	40	20
50cm	193	19	30	229	26	35	36
1m	208	28	27	222	29	30	14
2m	187	25	32	244	48	26	57

nately. It conforms to the principles laid down in tables I and III, and also shows that the difference between AR taken $F \longrightarrow N$ and

$N \longrightarrow F$ varies with the distance of F up to 12^m when N is constant.

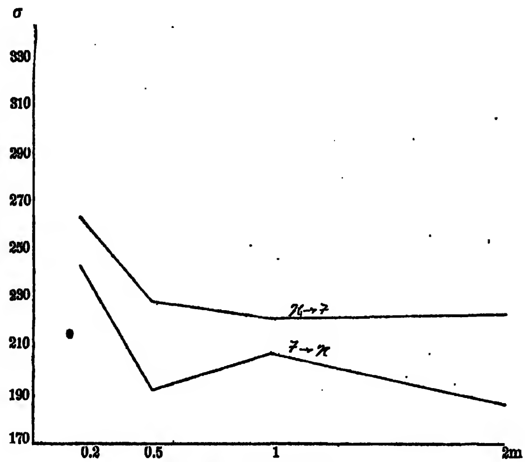


Fig. 25. Curve VI.

When F is constant, the difference between the AR taken $F \longrightarrow N$ and the AR taken $N \longrightarrow F$ varies inversely with the

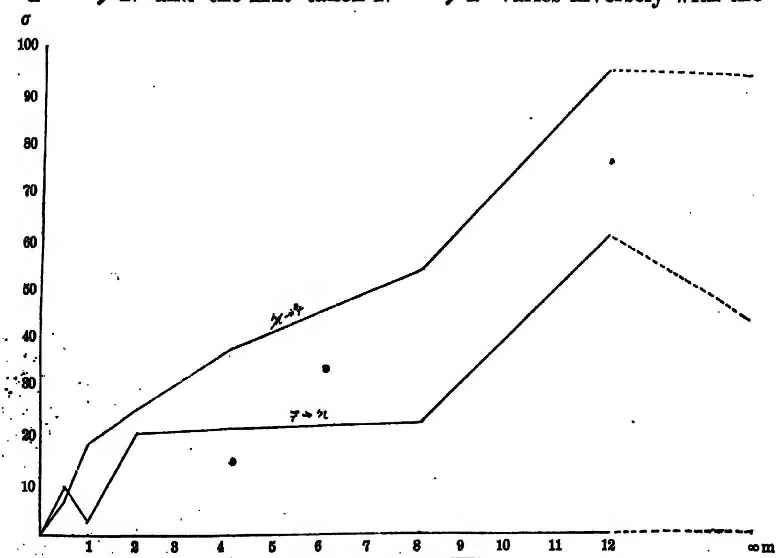


Fig. 26. Curve VII.

distance of N up to 2^m or more. This is complementary to table V, and confirms the same principles.

Curve V shows the difference in time depending on the direction of accommodation. This difference is further proved and illustrated by other data in curve VII, which is a comparison of the simple accommodation-time as given in tables and curves I and III. In the same manner curve VIII, complementary to curve VII, is a com-

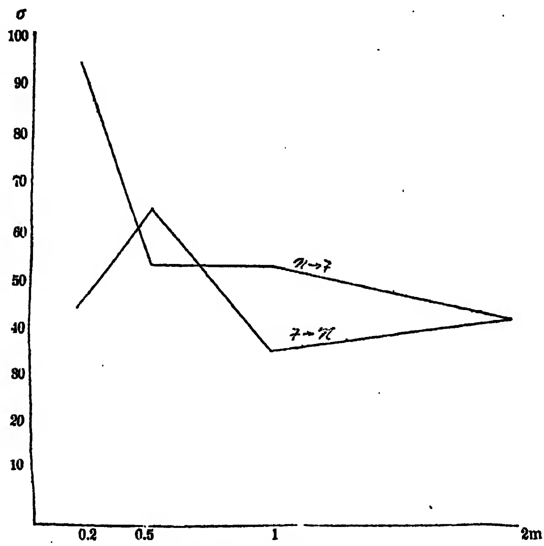


Fig. 27. Curve VIII.

parison of curves II and IV, and proves with *A* the same principle as curve VI proves with *AR*.

Aside from the time itself and minor conclusions which may be drawn from these figures, three important principles have been established.

(1) Within certain limits the accommodation-time varies with the distance between the points for which the eye is to be accommodated.

(2) It takes longer to change the accommodation from near to far than from far to near, and this difference in time varies directly with the length of the accommodation-time.

(3) For equal distances in the same range the accommodation-time is greatest for points near the eye and decreases with the distance of the points from the eye.

From the second fact arises the important question: what is it in the mechanism of the eye which will account for this difference in time depending on the direction of accommodation? It may be due

to the difference in time required for relaxation and contraction of the muscles controlling the lens, or to the difference in range of movement and sureness of adjustment in changing the form of the lens to focus for points at different distances from the eye. For a satisfactory answer to that question we must, however, look to further investigation on the physiology of accommodation.

COMPARISON WITH PREVIOUS RESULTS.

BARRETT'S apparatus consisted of a skeleton compound microscope, supplied with electric connections by means of which the time was recorded on a drum. The experimenter carefully pointed out and obviated many errors of previous workers, yet his apparatus necessarily involved three sources of error which have been avoided by the apparatus in the Yale laboratory.

(1) Instead of using lenses, as Barrett did, the eye was required to look directly upon the object to be accommodated for.

(2) His apparatus measured accurately to 0.1 sec. only, while the present apparatus measures with accuracy within ± 0.006 sec. That his apparatus not only contained some great error but also gave very inaccurate records, can be seen from the frequent remarks, "time too short too be measured."

(3) The greatest error is, perhaps, due to his method of deducing the simple accommodation-time. The present method of observing the reaction-time (without any movement of accommodation) to the same stimulus, for each distance and under exactly the same circumstances is the only trustworthy plan. BARRETT arbitrarily subtracted 0.4 sec. in all cases.

Additional records on six other persons, which have not been introduced into the tables, in order not to disturb their value for comparison, agree with BARRETT'S conclusion, that accommodation-time varies according to different circumstances, of which the principal are (1) age, (2) practice, (3) individual characteristics and (4) time of day.

In regard to fatigue, however, my results are contrary to the usual supposition. Experiments of some 300 accommodations in one continuous set do not support that theory. Fatigue soon sets in and may become very painful, but as long as the eye can accommodate clearly it causes a fluctuation in time which tends more to accelerate than to retard the velocity of accommodation.

The most surprising deviation from previous results and theories is the conclusion drawn from my tables as to the relation of velocity in accommodation between near to far and far to near. VIERORDT, AEBY and BARRETT all agree that the accommodation-time is greater than the relaxation-time, i. e. that it takes longer to accommodate from far to near than from near to far. This statement is contradicted by every table and diagram given above.

ON THE RELATION OF THE REACTION-TIME TO VARIATIONS IN INTENSITY AND PITCH

MORRIS D. SLATTERY, M.D.

METHOD OF EXPERIMENTING.

The plan followed was to place the person experimented on in an isolated room to which all stimuli were sent through wires from a distant room, and from which other sets of wires conducted the currents making electric registration in still another room.

The first requirement was thus a room free from disturbing lights and sounds; this was met by the construction of the isolated room. The isolated room is a small room built inside of another room; four springs of rubber and felt are the only points in which it comes in contact with the outer walls. The space between the walls is filled with sawdust as in an ice box. The room is thus proof against sound and light, and affords an opportunity of making more accurate experiments on the mental condition than yet attempted. This was the final construction of the room, adopted after numerous experiments. As such a room may prove valuable in physiological and medical work where freedom from disturbing sights and sounds is desired, it may be well to point out some of the difficulties to be overcome and erors to be avoided. The first requirement is a wall-surface impervious to sound. Owing to the great expense involved, such materials as asbestos, heavy tough hair-felt, lead, etc., could not be used; soft wood with outside packing of sawdust was finally chosen. The next requirement is that the sound waves from the building should not be transmitted to the frame work of the inner room, i. e. it must not be connected to the outer room. The nearest approach to the satisfaction of this requirement was made by supporting the inner room on pieces of soft rubber and avoiding all other connection with the walls of the outer room. The sound waves in the building are thus almost hindered from passing to the inner room. The vital importance of these precautions can be shown by simply laying a pencil across from the wall of the outer to that of the inner room; the various sounds are at once carried across and are heard in the inner room almost as loudly as if none of the other

precautions had been taken. The third requirement is the means of ventilation without sound conduction. After several trials a peculiar ventilator has been invented in which the air is made to pass back and forth through a tortuous passage, the walls and partitions in which are made of hair-felt. Sound waves can pass through bent tubes only by reflection from the walls and refraction around the angles; in the ventilator all reflection is killed by the non-elastic felt and the amount of sound transmitted by refraction through such a tortuous passage is so small that a person shouting into it at one end can barely be heard at the other.

The records were made by the graphic method, the usual chronoscope method being rejected as cumbersome and inaccurate. The counting of the fork-vibrations by the graphic method takes a somewhat longer time than the reading of the chronoscope records but in measurements of simple reaction-time this extra work is more than compensated by the saving on the laborious adjustment of the chronoscope and the necessary re-reckoning of the results. The new method of making graphic records, which was invented in the laboratory and used in the later experiments, not only greatly increased the accuracy of the records but made the work much less than that of taking chronoscope records. The apparatus used for recording was the same as that described by Bliss on pages 10–16.

In my investigations the multiple-key was connected with the isolated room and the apparatus in the following ways. The circuit from the tuning-fork through the time-marker was connected at one side to P and at the other to B, so that when P and B were in contact they short-circuited the current. This, of course, stopped all action of the marker while the contact was made, but as soon as the knob G was pressed the marker started. The circuit to the other marker was passed through the lever I to O and the platinum point, and out through Z and W, then to the reaction-room and through the reaction-key. As soon as the point of E touched U the lever I would break its contact at Z and immediately make it again at W, thus making a nick in the line of the second marker. As the stimulus circuit is closed at the moment E touches U this nick gives the moment of the stimulus. Since the current is immediately closed at W the marker is ready to make another nick as soon as the person reacting presses his key. The time-marker connected with the fork was set vibrating as soon as the knob G was touched, so that the curve was already being drawn before the record began. When the spark-coil is used the primary circuit is run over the same line as the

circuit used for the second marker; the secondary circuit has its poles in the drum and in the lever of the marker connected with the fork. Any movement at Z or of the reactor's key, produces a spark. Three different arrangements had to be adopted for the three variations of the stimuli to be used. These will be described in the appropriate sections.

Experiments with different intensities of tone.

In all the experiments on tones they were produced by electric forks in a distant room. The sound thus produced was sent from the primary circuit of a telephone transmitter, which was placed near the fork, through wires to the multiple-key. The secondary circuit of the transmitter was connected directly with the reacting telephone in isolated room. In investigating the relation to intensity of tones a fork of 250 complete vibrations per second was placed in the distant room. For producing variations in the intensity, a resistance-box was placed in the primary circuit of the transmitter; by this means a resistance of 100 ohms could be introduced, giving a weak tone, or 50 ohms, giving a medium tone or zero, giving a loud tone.

The first person experimented on was E. W. Scripture. With everything in readiness for the experiments the person entered the isolated room, closed and fastened the door, and, holding the reacting telephone close to his ear, waited for the stimuli to which he would react by pressing on the knob of the reacting-key. Thirty experiments were made in series of 5 to 10 with each grade of intensity, the order being varied to eliminate influences of practice and fatigue. After each series an intermission of at least 5 minutes was given. Preceding the sending of each stimulus a warning was sent to the reactor to call his attention to the expected sound.

After the first evening's experiment, the person experimented on made the following statement. "Left arm resting, with telephone in hand close to ear. Loudest sound, quite loud. Reacting hand at rest except index-finger which is held upon key-knob. After the warning, attention was directed entirely to expected sound. Eyes were closed and while waiting for sound were turned strongly toward the left. General condition slightly fatigued."

The next person experimented on was D. O'Keefe, the experiments being performed in the same manner as the preceding ones. His statement after the experiments was, "Left arm resting with telephone in hand close to ear. Loudest tone quite loud, the weak-

est tone being just perceptible. Reacting hand at rest except middle finger which was held upon key-knob. After receiving the warning, attention was turned entirely to expected sound. Eyes open and turned toward the left. General condition good." Before making the statement he asked, "if there was any trouble with the apparatus as the tone changed in intensity at different intervals." He was not aware of the fact that the intensity was to be varied.

The results of the experiment are summed up in table I.

TABLE I.

Unit of measurement=1^σ= .001 second.

	S′	MV	n	S″	MV	n	S‴	MV	n
E. W. S.	282	68	14	287	61	17	299	72	15
D. O. K.	249	57	34	212	70	29	218	68	10

The first column gives the person experimented on, the second the reaction-time to the strongest tone, the third the mean variations from the average, the fourth the number of experiments, the fifth, sixth and seventh give the data for the medium tone, the eighth, ninth and tenth those for the weakest tone.

It will be seen from the results that for the loudest sound, in the case of E. W. S., we have a reaction-time of 282^σ; for the medium intensity the reaction-time was 287^σ, for the tone of weak intensity the reaction-time was 299^σ. The absolute differences for different intensities were small and were much less than the amount of the mean variation. We can therefore conclude that they are practically equal and that within the limits of intensity used in these experiments the reaction-time does not vary with the intensity to any degree that can be detected.

In the experiments on D. O. K. it will be seen that the differences in the reaction-time are reversed but are also small; with sound of greatest intensity the reaction-time was 249^σ, with the sound of medium intensity the reaction-time was 212^σ, with sound of weak intensity it was 218^σ. From these results the same conclusion is to be drawn as from the previons ones.

Similar experiments had been previously begun in March, 1892, by Dr. Scripture at Clark University on F. B. Dresslar, but were not carried to completion. The sound was produced by a secondary coil

connected with a telephone and placed over a primary coil through which passed a current interrupted by the vibrations of a 250 tuning-fork. The angle which the axes of the two coils made with each other regulated the intensity of the sound, which was in all cases weak. Five steps with coils at angles of 110°, 125°, 140° and 155° were taken. The records of March 22 were handed to me by Dr. Scripture to be used, if I saw fit, in comparison with my experiments. They were counted and the results will be found in table II.

TABLE II.

Unit of measurement=1^σ= .001 second.

S′	MV	*n*	S″	MV	*n*	S‴	MV	*n*	S⁗	MV	*n*
288	26	30	239	18	28	224	25	29	268	15	30

The columns refer to the same subjects as in the previous table, but four grades of intensity were used. The strongest sound is placed first. The reactor, Mr. Dresslar, said in a note at the end of the experiments, "that he perceived no difference in the intensity of the various sounds, i. e. to his consciousness the different sounds appeared to him to be of equal intensity." While actually there was a difference in the intensity of the tone, it must have been very slight. A comparison of the reaction-times of the four steps taken shows such a slight difference that the only conclusion to be drawn from the experiments is the same as in the previous case.

That other observers have obtained very long reaction-times for very weak noises might be explained by the fact that when the warning signal is used shortly before the stimulus is to be produced there is a natural tendency to revive an image of the sound in the mind. In the case of loud sounds the image would give rise to no confusion, but in the case of very weak sounds the observer might well be in doubt as to whether a sound apparently heard was such a memory or was actually produced by a stimulus. Some experiments on the border line between sensation and hallucination indicate such an explanation.

In the table of results obtained from experiments performed by Wundt,[1] from which he concludes that the reaction-time decreases constantly with an increase in intensity of the stimulus, it will be seen that his figures do not bear out the statement. In his experiments the sound was produced by a ball falling from different

[1] Physiologische Psychologie, 2 ed., II 238.

heights; as the height increased, the noise became louder. His figures for successively louder sounds are 217$^\sigma$, 146$^\sigma$, 132$^\sigma$, 135$^\sigma$, 161$^\sigma$, 176$^\sigma$, 159$^\sigma$, 94$^\sigma$. It is at once apparent that with the exception of the weakest sounds, the results are in direct contradiction to the statement. It is but fair to add that these results are omitted from the later editions of the *Physiologische Psychologie.*

The experiments of MARTIUS[1] on tones and noises gave negative results, i. e., the reaction-times of the various experiments were nearly equal or showed slight and inconstant relations to each other. He drew the following conclusions: "There is no constant decrease in the reaction-time with an increase in the strength of the stimulus. Differences in the times occur only when very great differences in the strength of the stimuli exist, as for instance between a very weak and a very loud sound. The lengthening of the time with very weak stimuli can be accounted for by difficulty of perception."

My experiments on tones lead to these conclusions:

First—The law that the reaction-time decreases with increasing intensity of stimulus does not hold good for the sense of hearing, i. e. the reaction-time to tones is nearly the same for all moderate intensities.

Second—The longer time registered for very weak tones or noises by some observers is probably not due to any conscious change, but is caused by hesitation as to the actual hearing of the stimulus.

EXPERIMENTS WITH TONES OF DIFFERENT PITCH.

In using tones of different pitch the arrangement was nearly the same as in the previous case. Three forks were all kept ready so that in the few minutes of rest between the sets of experiments a change could be made from one to the other. The resistance was kept in the circuit and by preliminary trials the amount of resistance to be used for each tone was determined, so that all the tones seemed to be of the same intensity. This was quite necessary as it is impossible to adjust an electric fork so as to give the same intensity on different occasions. Similar precautions as to practice, fatigue, etc., were taken as in the previous case. The reactor seated in the isolated room heard the tones through the reacting telephone as before. The pitch of the tones was changed by changing the forks. Since the

[1] MARTIUS, *Ueber den Einfluss der Intensität der Reize auf die Reactionszeit der Klänge*, Phil. Stud. 1891 VII 469.

tones were adjusted so as to be of the same apparent intensity it would naturally be expected from the experiments of the preceding section that the reaction-times would be the same. The actual results are given in the following table:

TABLE III.

Unit of measurement=1^σ= .001 second.

P′	MV	n	P″	MV	n	P‴	MV	n
240	38	46	179	28	60	163	20	60

P′, P″ and P‴ denote the tones 100, 250 and 500 respectively. It is at once seen that the reaction-time decreases with the rise in pitch, a result which agrees with that of MARTIUS. The natural inclination is to explain this difference in the reaction-times by the supposition that 10 to 15 vibrations are required before the tone is perceived. If this supposition be true we should obtain the same reaction for all the tones by deducting the perception-time of each from its reaction-time. Suppose we take ten vibrations as representing the inertia of the sense organ; this would give us the perception-times, 100^σ, 40^σ and 20^σ for the three tones 100, 250 and 500 respectively. Subtracting these perception-times from the total reaction-times given in the table, 240^σ, 179^σ and 163^σ, we get the remainders 140^σ, 139^σ and 143^σ. These remainders fall within the limits of variation and are to be regarded as the same. My results are thus in harmony with the supposition mentioned. MARTIUS obtained results which agree with mine in the fact that the reaction-time decreases with a rise in pitch, but this decrease could in no way be brought into harmony with the supposition that a constant number of vibrations was used up in the latent time.

The conclusions to which my experiments lead are as follows:

First—The reaction-time to tones decreases as the pitch rises.

Second—The view held by EXNER, VON KRIES and AUERBACH and rejected by MARTIUS,—namely, that about 10 vibrations are necessary to the perception of a tone, no matter what its pitch,—is sufficient to explain the differences in the reaction-times for different tones.

EXPERIMENTS WITH ELECTRICAL STIMULI OF DIFFERENT INTENSITIES.

In using electric stimuli the current of the primary circuit after passing through the inner coil was sent through one of the prongs of a fork, kept vibrating electrically, by which it was interrupted at

each vibration. From the fork it was sent through a rheochord composed of seven lengths of wire. Hence it passed to binding posts 2 of the multiple-key mentioned above. The other pole of the battery was connected to binding post 3. When the key is pressed, the circuit is completed. The secondary coil was connected with two electrodes in the reaction-room. One electrode was of zinc covered with cloth, the other of sponge; both were moistened with a solution of common salt. The other arrangements were the same as in the previous cases. In these experiments the spark-coil was used and the same precautions as observed in former experiments were adopted.

As soon as the multiple-key is pressed the current passes through the primary circuit, being all the time interrupted 100 times per second by the electric fork. This causes a current to pass through the secondary circuit and the person in the isolated room receives 100 shocks per second. As soon as he perceives the shocks he is to react in the usual way. The time is measured between the moment of closing the primary circuit and that of reacting. The intensity of the stimulus can be regulated either by moving the secondary coil nearer to or further from the primary or by weakening the primary current. The former method was not suited to the single experiments but was used to regulate the shock permanently to any desired intensity. Then the different intensities were produced by adjustment of the amount of wire introduced on the resistance-board.

During the experiments six steps of different intensity were taken. The greatest intensity was obtained by shoving the secondary coil sufficiently near to the primary coil until a shock was produced which was not strong enough to startle the reactor and thereby interfere with the reaction-time. When a variation in the intensity of the stimulus was desired, the clamp was transferred to another wire on the resistance-board, causing an increase of resistance of two feet of the wire with each step. When the clamp was on wire No. 6, a resistance of 12 feet of fine German silver wire was thus inserted and a very weak shock was produced.

The experiments were performed in the same manner as the preceding ones. A warning was given previous to each stimulus. The reactions were repeated at intervals of 15 seconds, until a record of 30 reactions was taken, after which a rest of five minutes was given to the reactor. The person experimented on was E. W. Scripture.

The results are seen in table IV.

TABLE IV.

S^{I}	MV	n	S^{II}	MV	n	S^{III}	MV	n	S^{IV}	MV	n	S^{V}	MV	n	S^{VI}	MV	n
137	21	19	135	26	15	155	29	17	180	46	26	220	61	24	210	61	22

S^{I} is the shock of greatest intensity; S^{II}, S^{III}, S^{IV}, S^{V}, S^{VI} represent shocks of lesser intensity, S^{VI} being the weakest; otherwise the abbreviations are the same as used in previous tables.

It will be seen that there is a slight but constant decrease in the reaction-time with an increase in the intensity of the stimulus. These results coincide with those obtained by other observers.

The conclusion to be drawn seems evident, namely, that in the domain of tactile stimulation by electricity the reaction-time decreases with the increase in the intensity of the stimulus.

EXPERIMENTS ON THE MUSICAL SENSITIVENESS OF SCHOOL CHILDREN

J. A. Gilbert.

Bodily measurements of children have been repeatedly made; their laws of bodily growth have been empirically determined; most important deductions for the equipment and management of schools have been made from them. The senses and intellect of school children have received less attention; most of the work has been confined to investigating the sharpness of vision, the acuteness of hearing (deafness) and the memory powers. The musical sensitiveness has never, I believe, been tested.

By musical sensitiveness is meant the least noticeable difference in the pitch of a tone. Those who can detect a small difference in pitch between two successive tones are more sensitive than those who can detect only larger differences.

Apparatus and methods.

Since the object of the present investigation was not to determine the least perceptible difference in relation to tones of various pitches but was to compare children with one another, a single tone was used throughout the experiments, namely, the tone $\bar{a}=435$ of international pitch. The method was that of minimum gradation. Each experiment was composed of two tones and a judgment as to their likeness. The tone $\bar{a}$ was first sounded, then a tone $\frac{1}{32}$ of a tone higher; the child answered "same" or "different;" $\bar{a}$ was again sounded, then a tone $\frac{2}{32}$ higher; and so on, the second tone being raised $\frac{1}{32}$ each time, until the child had several times declared the tones to be different. Thereupon the second tone was started at the same pitch as the first and in like manner successively lowered. The number of thirty-seconds of difference that were just perceived was noted in the two cases; the average gave the result for a single experiment. Ten experiments were made on each child. The child

was left entirely ignorant of the method of performing the experiment, so as to avoid suggestion of any kind.

The instrument used in making the experiments was composed of an adjustable pitchpipe with an index-arm moving over a large scale.

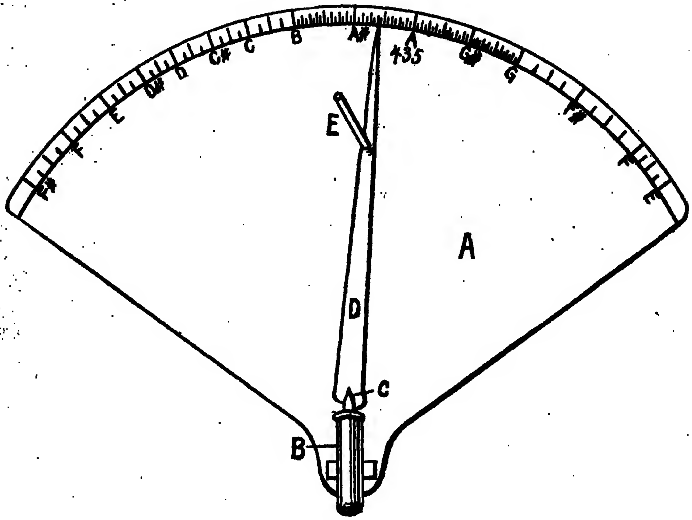


Fig. 28.

The instrument, which may for brevity be called the tone-tester, is shown in figure 28. The fan-shaped plate A is supported by a handle beneath it. The pipe B, fastened to A, contains a vibrating reed whose length is regulated by a tightly sliding clamp, the projecting rod of which is shown at C. This clamp is moved by a lever whose long arm D, with the handle E, extends out over the plate. It is readily seen that, for each different position of the point of the long arm, the vibrating reed will have a different length and the tone produced will be different in pitch. It is also evident that a small difference in pitch corresponds to a large movement of the point of the long arm.

The points on the index for each tone and half-tone were determined by direct comparison with a carefully tuned piano of a piano-dealer. These larger divisions were then divided proportionately into sixteenths. As the large divisions were into half-tones, these divisions corresponded to thirty-seconds of a tone.

The accuracy of the results depended on the accuracy of the instrument and the accuracy of the method. The possible errors of the instrument were as follows: error of tuning, error of graduation, and two errors of change in pitch.

The readings of the instrument must be accurate to 1 unit of the scale ($\frac{1}{32}$ of a tone). The largest allowable error in the instrument is thus $\frac{1}{2}$ a unit of the scale.

As the tuning was performed by observing the freedom from beats, the error from this source could not be above a tenth of a beat per second. The half-tone $\bar{a}$ to $\bar{a}\sharp$ corresponds to nearly 26 vibrations per second; half a space of the scale would indicate about $\frac{8}{8}$ of a vibration. The error is thus less than $\frac{1}{4}$ of a space.

The intermediate graduation was done by eye, and was unquestionably accurate within $\frac{1}{4}$ of a space.

The first error of change in pitch is the error that might be introduced by back-lash in the joint between the levers. To avoid this the lever was always started beyond $\bar{a}$ and moved up to it in the direction in each experiment. With this precaution the error is same practically zero.

The change of pitch due to changing intensity of the blast was mainly eliminated by practice in blowing the pipe. The residual could not be determined, but it was probably negligible in comparison with the others.

All the residuals are much less than the required amount. Their sum was unquestionably within the limit set, and the requirements of precision in the instrument can be said to have been satisfied.

The sources of variation due to mental influences were as follows: influence of the judgment of pitch by changes in intensity, influence of suggestion.

Judgments of pitch are generally made quite without regard to intensity. Measurements of the influence of changes of intensity on the judgments of pitch have never been made; but as great care was taken in blowing the apparatus and as the adult experimenter could regulate the sound with an ear so much finer than that of the children, the variation was probably negligible. Otherwise it enters as one of the factors into the mean variation given in the table.

All chances of suggestion had to be avoided. Children are inclined to follow, almost unconsciously, the slightest indication in making their decisions. Those of the ages nine and upwards were dealt with in groups, each making upon a paper an equality-sign when the two tones seemed the same to him and a cross when they

seemed different. Children of six, seven and eight years of age had to be dealt with individually for fear that they would be influenced by their companions and would not be reliable in their marking. All results were very satisfactory with the exception perhaps of three children aged six whose data were somewhat uncertain on account of lack of attention, independence and decision, or perhaps from the excitement, fear and novelty of the undertaking. These influences of suggestion and distraction are probably the main factors in the mean variations.

Experiments.

Five boys and five girls of each age except 18 and 19 were experimented upon. For the ages 18 and 19 it was possible to obtain only girls. In computing the results the average of all the experiments for a given age was first obtained. The mean variation from this result was noted. Then the children of that age were considered separately, the mean variation from the result for each child being computed. Finally the average of these mean variations was taken. This can be illustrated as follows. Let

$$\begin{array}{llll} a_1, & a_2, & \ldots\ldots & a_{10} \\ b_1, & b_2, & \ldots\ldots & b_{10} \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ j_1, & j_2, & \ldots\ldots & j_{10} \end{array}$$

be the results for ten children of a given age. The total average will be $(a_1+a_2+\ldots+a_{10}+b_1+b_2+\ldots+b_{10}+\ldots+j_1+j_2\ldots+j_{10})\div 100$; this is the result given in column D of the table, the first decimal place of the average being retained. The mean variation of the separate measurements obtained in the usual way is given in the column headed MV. This mean variation can be used as an index of the accuracy of the result. The results for each child were obtained by taking the averages $(a_1+a_2+\ldots+a_{10})\div 10=a$, $(b_1+b_2+\ldots+b_{10})\div 10=b$, $\ldots\ldots$ $(j_1+j_2+\ldots+j_{10})\div 10=j$. The average of these averages is, of course, the same as the total average. The mean variations for $a, b, \ldots, j$ are then calculated; these mean variations will indicate how much the child's judgments fluctuated owing to the conditions of attention, suggestion, etc. To get at the average effect for the given age the average of these

mean variations was taken; this is given in the table in the column MV′. The last column in the table gives the number of experiments for each age.

TABLE.

Age	D	MV	MV′	n
6	12.3	1.38	1.76	100
7	9.1	.89	3.60	100
8	6.8	.90	1.29	100
9	4.8	1.09	1.14	100
10	6.2	.68	.77	100
11	4.8	1.09	.89	100
12	4.1	.99	.45	100
13	3.7	1.26	.46	100
14	3.5	.97	.94	100
15	5.	1.03	1.11	90
16	4.	.91	.68	50
18	2.6	.74	.93	60
19	2.4	.84	.62	140.

D, least perceptible difference in 32nds of a tone.
MV, mean variation for total result.
MV′, average of mean variations for separate children.
n, number of experiments.

The relation of the size of the least perceptible difference to the age is shown in the accompanying curve, fig. 29, in which the figures

on the horizontal axis indicate the ages, those on the vertical axis the least perceptible differences.

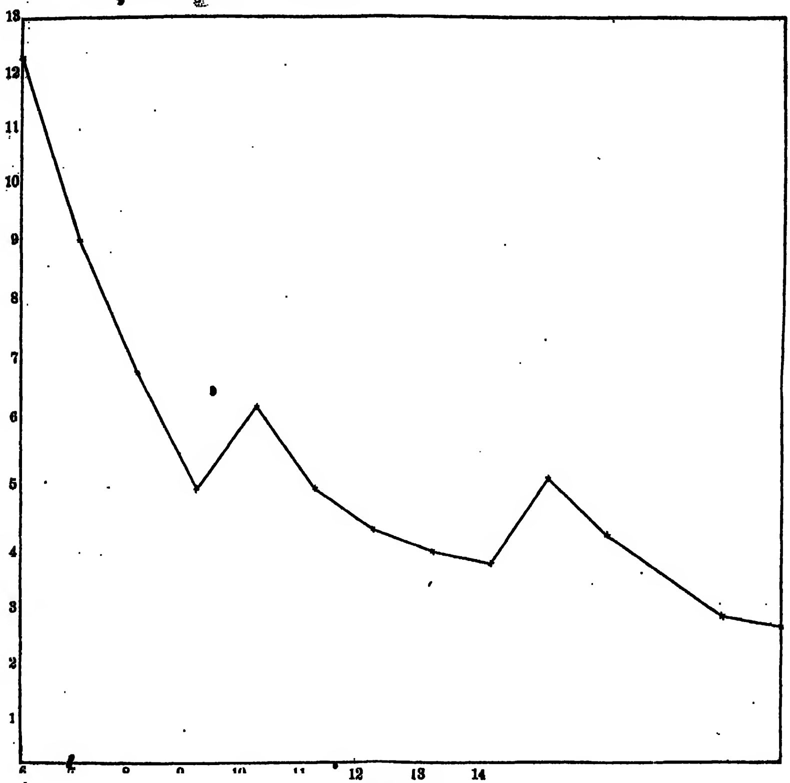


Fig. 29.

Conclusions.

1. The primary aim in taking up this problem was to discover if there were any who could not distinguish to a half-tone, and if so, to determine the proportion to the total number. The question was of practical importance. Any such children could not, of course, receive the same instruction in music; if the proportion below a certain age were large, musical intelligence could not be expected in the earlier ages.

The results show that the children are fully capable of the task expected of them. The least sensitiveness occurs with children of six years where the average least perceptible difference is 12 thirty-seconds or $\frac{3}{8}$ of a tone. Of all the children examined there were only three individuals whose average exceeded half a tone.

2. It is at once seen that the least perceptible difference decreases with increasing age, i. e. the sensitiveness increases. The sensitiveness increases at first rapidly, but finally becomes almost stationary.

It is a pedagogical principle that the child develops more rapidly during the first ten years of its life than at any other time. Tone discrimination offers no exception to the rule; in the three years from 6 to 9 the child gains in discriminative sensibility more than twice as much as in the whole of the ten years thereafter up to the age of 19. The contrast increases as the number of years taken into consideration is greater, for the child gains more in the three years from 6 to 9 than it can possibly gain during the rest of its life-time.

3. Judging from the way in which mind and body develop under education it would naturally be inferred that the discriminative ability of the child would increase regularly with advance in age. At the ages ten and fifteen, however, occur very abrupt changes. In order to verify the data for those points I repeated the trials on the years nine, ten and fifteen with increased numbers in each age but the second average result varied only 0.3 of a thirty-second from the first average, showing that the curve was true to the facts so far as could be detected.

A similar change in the curve apparently occurred at the age of twenty, but as I only had three subjects of that age I did not feel justified in adding the result to the table, yet this seemingly similar jump at twenty—a leap in the curve from 2.4 up again to 3.2—adds credence to the supposition that there is some periodic change causing it. After twenty years the curve seems to drop again as it did after 10 and 15, but here also the number of persons was insufficient to justify establishing a point on the curve.

It will be noticed that the sudden changes divide the curve into uniform portions from 6 to 9, from 10 to 14 and from 15 to 19.

An explanation for this loss of sensitiveness at certain ages seems difficult.

The change at fifteen is more easily explained, perhaps, than the one at ten, as that is the age at which puberty shows its effects on the system. Although these influences cannot be placed at one certain year, the average lies at 14 years and five months.[1]

Possibly the second teething which occurs at 9 to 12 years of age may have such an influence on mental life as to cause a loss of sensitiveness.

[1] Eighth Annual Rept. Mass. State Board of Health, 1877, p. 284, Table No. 16.

Similar decreases in ability are to be seen in the results obtained by BRYAN.[2] There is a marked difference between the data of the two periods 9–10 and 14–15 from the data of the other ages. Also in the charts at the close of his article there is an almost invariable change in his curves at the ages 10 and 14, showing that his subjects labored under some set-back or disadvantage at those ages.

---

[2] BRYAN, *On voluntary motor ability*, Am. Jour. Psych. 1892 V 160, Table VII.

A NEW REACTION-KEY AND THE TIME OF VOLUNTARY MOVEMENT

BY

E. W. SCRIPTURE and JOHN M. MOORE.

In an article on the skin-sense[1] DESSOIR describes an arrangement for use in place of the ordinary telegraph-key in investigating reaction-times. In addition to the gain in convenience he claims that the varying results obtained for sensory and muscular reactions are due to the effect of the construction and manner of use of the ordinary key on the time of executing voluntary movements.

At the request of Prof. Titchener of Cornell University a rough copy of DESSOIR's arrangement was made in our laboratory workshop. It became evident that this arrangement possessed only one good quality, that of portability; with it the arm and hand did not need to be upon a table as with the telegraph-key but could be placed in any comfortable position. With this exception all the disadvantages of the telegraph-key were retained and some further ones added.

The advantage of portability is so great that the problem of the invention of a key that could be used in any position was undertaken. At the same time certain faults of the telegraph-key were to be avoided. There was to be no spring; the key was to act on the make or the break or on both; each contact was to be applicable to either a flexion or an extension movement.

The problem was solved with success. The final form in which the key was made, is shown in fig. 30.

Two hard-rubber slides run on steel guides. The upper slide has a hole to fit the end of the finger. The other has an inclined hole for the thumb, for use when the key is held by the thumb and finger alone. When the key is rested on anything or is held by the other hand, the thumb may be placed against the projecting arm; this arrangement gives a somewhat easier action, as the finger moves more naturally in a plane inclined to that passing through thumb and finger.

---

[1] DESSOIR, *Ueber den Hautsinn*, Du Bois-Reymond's Arch. f. Physiol. 1892 309.

The binding-post shown at the top carries a platinum contact; that on the upper slide is connected with a contact at each side of the slide; that on the lower slide is connected with a contact pointing upward. The lower slide is fastened at any point by a clamp whose screw is seen to the left in the figure. This determines the range of movement of the upper slide.

The upper slide can make contact at either extreme of its movement. One wire is always carried to the binding-post on the movable slide. To have a break-circuit record with a flexion movement, the other wire is carried to the top binding-post; the thumb and

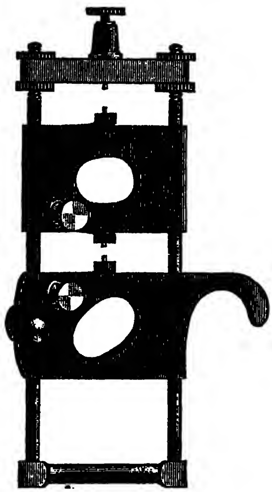


Fig. 30.

finger are held apart at any desired distance; at the least movement of the finger the current is broken. For a break-circuit record with extensor movement the other wire is carried to the post in the fixed slide; the finger is bent till the slides touch. For make-circuit records the lower contact is used with the extended finger, the upper with the bent finger. As the excursion can be made very small by adjustment of the lower slide, the lost time for make-records can be reduced to a minimum.

No spring for holding the contacts is needed. The movable slide is brought into position by the finger and will retain its contact without pressure until disturbed.

While using this key in an exercise on the rapidity of tapping movements of the finger we found that we had the means at hand of making new investigations on the time and extent of voluntary

movement. All previous work in recording taps had been done with an ordinary telegraph-key by which only the moment of the extremity of the downward movement was recorded. By simply connecting the binding-posts of the cross-piece and the fixed slide to one end of the circuit and the post of the movable slide to the other, a record was made of the downward extreme, the upward extreme and the period of rest at each extreme. Moreover, the adjustment of the fixed slide gave any desired extent for the movement.

The method of recording was that described by BLISS on pages 7–10. The key was placed in the primary circuit of the spark-coil and the secondary circuit was sent through the drum and fork. A 500 fork was used, each half-wave indicating 1^{σ}. A spark-record was made of the kind shown in fig. 6. Records were counted in thousandths, no account being taken of fractions of a half-wave.

The subject of experiment, J. M. Moore, was placed in the isolated room described on pages 2 and 71. The arm rested easily on a table of convenient height. A rod clamped to the table acted as a support for the hand. The rod was grasped by the fourth and fifth fingers, whereby the motion of other muscles than those of the fore finger and thumb was in the main prevented. Three distances were chosen through which the slide was to move, namely, 5^{mm}, 10^{mm} and 20^{mm}. Two series of experiments were made on each distance. The results were combined into the accompanying table.

TABLE.

Distance	E	MV	F	MV	C	MV	*n*
5^{mm}	33	4	48	8	81	9	70
10^{mm}	40	5	48	9	88	9	60
20^{mm}	53	4	37	5	90	5	40

In this table E indicates the average time of the extensor movement, F that of the flexor movement, C that of the complete movement, MV the average deviation and n the number of records in each case.

With the distance of 5^{mm} the extensor movement required less time than the flexor movement and was much more regular. With 10^{mm}

there was a similar, but smaller difference; the limits of average deviation show that in many cases the slower extensor movements took longer than the faster flexor movement. With 20^{mm} the flexor movement was much more rapid than the extensor movement. It is evident that the point at which they require the same time lies somewhat above 10^{mm}.

These results can perhaps be explained in the following way. When the key was in position the middle finger was placed on the upper cross-piece while the fixed slide was held by the thumb. So whatever the distance, the fore-finger was always brought back to the same bent position. Now, when the distance is very small the finger is never fully extended; thus the extensor muscle has abundant leverage to do a little work in a very short time, while the flexor is not so favored. As the distance increases the flexor slowly gains its power—slowly, because it had never been bent enough to obstruct its movement materially. But while the flexor is slowly increasing in strength, the extensor is losing quite rapidly, for only a few centimeters will fully extend the finger so that its whole power will be lost. When the distance is 10^{mm} the two powers are nearly equal, but with the excess in favor of the extensor. At 20^{mm} the balance of power has changed, and the extensor is so near the end of its strength as to show clearly in the results.

A curious result of the gain in one muscle and the loss in the other is the fact that the total time of vibration, or tapping, varies only about 10 per cent. for distances standing in the relation of 1 to 4.

The time of rest was quite different at the two positions. At the end of the extensor movement the make-spark and the break-spark indicated a period of 2^{σ} to 3^{σ}, occasionally 4^{σ}. At the end of the flexor movement the time of rest was so short that seldom more than one spark was present, indicating a time too short for detection.

In looking over the single records it was found that the time of movement was much more regular than the introspective observation had indicated. At times the observer seemed unable to move the muscle; some unusually long times are found in the record but not so often as the observer supposed.

DRAWING A STRAIGHT LINE: A STUDY IN EXPERIMENTAL DIDACTICS

BY

E. W. Scripture and C. S. Lyman.

"The ignorance of the ancients in regard to the art of experimenting, or the low state of development which it reached with them, is one of the causes why their physics lagged so much behind," says Poggendorff in his Lectures on the History of Physics. In comparison with such sciences as mathematics and astronomy physics has achieved most of its progress in modern times. In the very latest times the experimental methods have been carried over from the general science of physics to the technical sciences dependent on it; the science of electrical engineering is built on experiments and measurements, partly taken from the physical laboratories but also to a great extent carried out by practical men for practical purposes.

In psychology the first real progress since Aristotle began when Fechner showed the possibility of experimental methods. "With the introduction of experiment, the trustworthy application of the method of introspection became for the first time possible" (Wundt, Physiol. Psy., 4 ed., I 4). Psychology to-day is a science of experiment and measurement. The time seems at hand when applied psychology should also become an exact and trustworthy science. Pedagogy, or the science of education, is in great extent based on psychology. It will not, however, do to wait for the crumbs that fall from the psychologist's table; he is thinking of other matters than practical applications. Pedagogy, moreover, has its own peculiar problems which must be solved in special ways. Can pedagogy make use of experiments in solving any of its problems?

We have chosen such a simple matter as the drawing of a straight line and have tried to gain information on the subject by making experiments. The main object was to see if we could really experiment on a pedagogical subject; at the same time we hoped to make a contribution to our knowledge of methods of drawing. No wide generalizations have been attempted; we have gathered a few facts and drawn the proximate conclusions from them. We firmly

believe, however, that not only can other questions that arise in regard to drawing be settled by experiments conducted in the proper way, but also that the same method can be extended with little difficulty to innumerable questions that arise in education.

Ten boys of the upper grammar grade of the school of Manchester, Conn., were chosen so as to be of as nearly the same age as possible, the average age being 13 yrs. 3 mos. They had had some instruction in drawing throughout the various grades, but not to such an extent as in the city schools; some of them from the country districts had had very little.

The boys all sat at their desks in just the same positions. A sheet of paper 7 in. long by 4 in. wide was placed before each. In the middle of the sheet were two dots 100^{mm} apart lengthwise of the paper. At a given signal each boy drew a straight line between the dots. Afterwards a ruler was laid on each sheet so that its edge cut the dots. With a pair of dividers the greatest deviation of the line drawn from the true straight line was found. The dividers were then applied to a scale and the results recorded in millimeters, the tenths of a millimeter being estimated. The additional figure was retained in the averages, the last significant figure, however, is tenths of a millimeter.

The experiments were performed under certain sets of conditions. In the first sets the boys sat squarely in front of the desk, holding the pencils in the usual way grasped near the middle. The line was drawn with a single movement of the pencil, without going over it a second time or erasing. The first line drawn was horizontal, i. e. parallel to the front surface of the body. On the second set of papers the line drawn was vertical, the other conditions remaining the same. In the third set the line was 45° to the right, in the fourth 45° to the left. The positions of these lines can be thus shown: 0° 270° 45° 325°. The arrows indicate the direction of movement of the pencil. In calculating the deviations, or errors, those deviations toward an excess of the angle were called +, those toward the primary position of the line −; in the table the corresponding terms, over, under, to the right and to the left are added. The total error Σ is the difference between the maximum + deviation and the maximum − deviation, i. e. the amount of the + deviation added to the amount of the − deviation. It is not the distance between the extremes of the deviations of the same line.

In further sets of experiments the position of the boys was changed, the right side being placed toward the desk. Still other

TABLE.

Varied condition	0° + over	— und'r	Σ	45° + left	— right	Σ	270° + right	— left	Σ	325° + right	— left	Σ
Facing, mid grip, steady	0.86	1.10	1.96	0.75	1.61	2.36	1.24	0.51	1.75	1.16	2.36	3.52
Right side, mid grip, steady	1.10	0.51	1.61	2.22	0.43	2.65	1.41	0.94	2.35	1.06	1.64	2.70
Facing, near grip, steady	0.56	1.43	1.99	2.06	0.76	2.82	0.88	1.20	2.08	0.76	1.75	2.51
Facing, far grip, steady	0.53	1.12	1.65	1.66	0.31	1.97	1.14	0.63	1.77	1.30	1.67	2.97
Facing, mid grip, progressive	1.24	0.94	2.18	0.96	1.45	2.41						
Facing, near grip, progressive	1.33	0.79	2.12	1.16	1.03	2.19						
Facing, far grip, progressive	1.40	1.15	2.55	1.16	1.07	2.23						
Average	1.00	1.01	2.01	1.42	0.95	2.37	1.16	0.82	1.98	1.07	1.86	2.93

sets were the same as the first excepting the grip, the pencil being held near the point. In the next sets the pencil was held far from the point, otherwise the conditions were the same as in the first set. In the next three sets the lines were drawn by progressive movements instead of a steady movement. Two inclinations were chosen, 0° and 45°. The first set was done with the middle grip of the pencil, the second with the near grip, the third with the far grip.

Some experiments were tried with other positions than those of facing and right side, but the positions were so awkward that no results worth tabulating were obtained.

From the results given in the table we can draw a number of conclusions. The facing position is more favorable for horizontal (1.96) and vertical lines (1.75) than it is for inclined lines (2.36, 3.52). The right-side position is also more favorable for horizontal (1.61) and vertical (2.35) than for 45° (2.65) and 325° (2.70). This is what we might expect as a result of Listing's law according to which the

eye moves more easily upward, downward, right and left (i. e. vertically and horizontally), than in intermediate positions.

In drawing horizontal lines and 325° lines the right-side position is more favorable than the facing position; for the others facing is preferable. This is perhaps to be explained by the fact that the fore arm swings around the elbow in a curve which in order to produce a straight line must be compensated by a backward and forward movement of the upper arm around the shoulder. In the facing position with the paper directly in front the fore arm touches the body at the start and the hand is bent at the wrist. As the arm moves, it becomes freer and a more natural position is assumed. This change in the manner of carrying the arm would tend to introduce uncertainty into its movements. With the arm raised upon the desk in the right-side position it is brought clear of the body, and the line can be executed in one sweep. In drawing the 45° line the arm is just as free in the facing as in the right-side position and we find little difference in the results. In drawing the vertical line we would naturally expect much greater accuracy when the motion is a simple forward or backward movement of the arm around the shoulder, as in the facing position, than when the arm has to undergo complicated adjustment with the elbow raised. Why there should be a difference with the 325° line it seems impossible to say. Both positions, facing and right side, are on the whole equally favorable for accuracy, as can be seen by taking the average of the total errors, Σ, 2.40 for facing, 2.33 for right-side.

Holding the pencil far from the point is in general the most accurate method (average of Σ 2.09); near the point is as accurate as the middle grip (2.40). With the pencil far from the point the line is drawn with a smaller movement of the hand, which would give a better result than a larger movement requiring adjustments from elbow and shoulder. For horizontal lines the far grip is the most accurate (1.65 against 1.96, 1.99); for 45° the same is true (1.97 against 2.36, 2.82); for vertical lines the middle and the far grips are the same (1.75, 1.77), the near grip is unfavorable (2.03); for the 325° line the near grip is the best (2.51), the far grip is next (2.97), the middle grip is very unfavorable (3.52). That the 325° line forms an exception to the advantages of the far grip and is much less regular than the others, is evidently connected with the awkward contraction of the fingers in this direction.

In progressive lines experiments were made only on 0° and 45°. With the middle grip the result is less accurate for both horizontal

(2.18 against 1.96) and inclined lines (2.41 against 2.36) than for steady lines. With the near grip it is less accurate for horizontal (2.12 against 1.99) but more accurate for inclined lines (2.19 against 2.82). With the far grip it is much less accurate for both (2.55 against 1.65; 2.23 against 1.97). In general we would expect a progressive line produced by complicated movements to be less accurate than a steady line. This is the case except in the inclined line with near grip; for this exception we are unable to find any reason.

When we compare the two kinds of errors + and — we find that for 0° they are in general equal (1.00 to 1.01). In the facing position with the steady line the — error is larger, the + errors being 0.86, 0.56, 0.53, the — errors being 1.10, 1.43, 1.12. With the progressive line the reverse is the case: + errors 1.24, 1.33, 1.40; — errors 0.94, 0.79, 1.15. In general the facing position gives a tendency to — errors, the right-side position to + errors.

With the 45° lines the general tendency is to + errors (1.42 against 0.95). This is to be expected as the 45° line is an arc drawn by the forearm with a correction introduced by the upper arm; when we try to draw two arcs of a circle instead of the straight line we generally make the  arc too curved and the  too flat. With progressive lines the tendency is for some reason just the reverse but is in general much less. In the right-side position there is an overwhelming tendency to + errors (2.22 against 0.43).

With the 270° lines the general tendency is to + errors. The middle grip and the far grip give + errors, the near grip — errors.

With the 325° lines the — errors predominate in almost every case.

It is interesting to note which inclinations give on the whole the most accurate lines. By comparing the values for Σ we find that the most accurately drawn line is the 270° or downward vertical line and the least accurately drawn the 325° or left inclined line.

The reasons for many of these facts are still greatly matters of conjecture to be settled only by careful investigation of the action of the separate muscles of the arm and eye in each case.

SOME NEW PSYCHOLOGICAL APPARATUS

E. W. SCRIPTURE.

In starting the Yale laboratory it was deemed best to provide ample facilities for the repair and construction of apparatus by establishing a serviceable workshop-equipment. In addition to the large amount of work done for the investigators of special problems, several pieces of apparatus of general use were invented and manufactured. Some of these, the multiple key (first model), the reaction-key and the switch-board have been described in the preceding pages. There are, however, three others that are deserving of mention.

In the first model of the multiple key, the two levers were hung on different axles; consequently the arcs described by the contact-points were not concentric. For most purposes this made little or no difference. For two of the numerous uses of the key it appeared quite desirable to avoid this difference of centers. In the first place it is geometrically evident that in using the contact E-U (fig. 11) the upper point will slide sideways slightly as the key is depressed. This makes slight variations in the resistance to the current passing through the points. These variations are not noticeable except in a telephone-circuit; there the result is to produce a grating noise in addition to the tone or noise sent through the telephone. The other objection is a somewhat similar one in regard to the contact D-S-T. The point T slides along the spring S and causes variations in the strength of the current.

To remove these objections a new key was built in which the lower lever works around the same axis as the upper one, so that any point of the upper lever striking the lower one will always touch it at the same place, no matter how far it is moved.

The new key is shown in fig. 31. The lower lever has two projecting arms that are hung on the axle of the upper lever. There is no necessity for the spring S (fig. 11) in the first key; consequently both contacts 7 and 3 are alike. Experience having shown the mercury cup to be better than the contact N-R of the first key, the latter has been omitted. Figures opposite the various contacts indicate the binding-posts to which they are connected.

The vital point in the construction of the key is the concentricity of the levers. In the one already made for Clark University this has been carried out so well that both sets of contacts 7–8 and 3–4

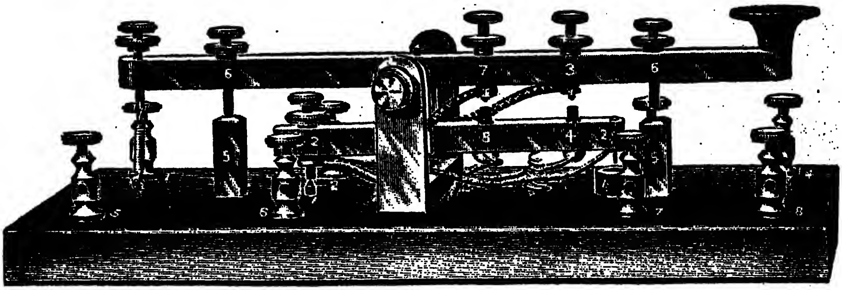


Fig. 31.

can be adjusted to strike at the same time and maintain their contact through an arc of 10°. The rubbing of the upper contact against the lower one, as tested by the telephone, has been totally eliminated for 7–8 throughout the arc and for 3–4 throughout a somewhat smaller one.

Another piece of apparatus constructed is a pendulum-contact.

Those who have used mercury contacts for clock-pendulums well know the continual trouble that they give when placed in the center of the arc of swing at the extremity of the pendulum. Relief has been sought by resorting to platinum contacts made when the pendulum is at the extremes of its arc. The sources of error in this method have made it almost inapplicable in scientific work.

After wasting considerable time and money in these two ways, a contact-apparatus was invented which made platinum contact in the middle of the arc of swing. In this way the advantages of solid contact and mid-arc contact were gained together.

This clock-contact is shown in fig. 32. The support A carries the horizontal metal piece B with the binding-post C. The rubber block D; fastened to B, carries the metal arm E, which by means of its axle is in contact with the binding-post F. At the end of E there is a platinum point G which rests on another platinum point at the end of the screw H. This instrument is placed on the floor of the clock just far enough in front to clear the pendulum. A fine wire I is run from the arm E to a pin on the pendulum-arm J. If H is adjusted so that the platinum points just touch when the pendulum is at rest, any movement will break the circuit. When the pendulum is swinging, contact is made only at the lowest point of the arc.

Owing to the light weight of the parts and the smallness of the movement, the friction is exceedingly small.

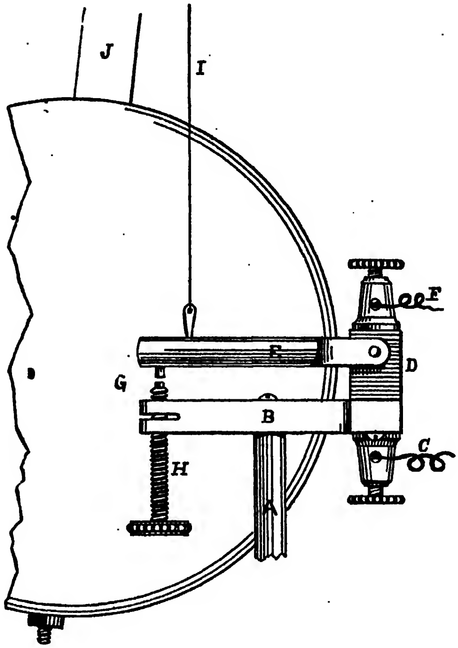


Fig. 32.

The third instrument to be described is a new chronograph. The electric drum mentioned by BLISS on p. 9 was a temporary arrangement which did such excellent service that the construction of a thoroughly durable apparatus was decided upon.

The drums used for physiological work, such as the Baltzar kymograph, are made to run at slow rates of speed. Those used for physical purposes, such as the König drum, are not made for continuous running. For psychological work there is need of a very rapid drum running continuously as long as desired. In the WUNDT[1] chronograph a high rate of speed is obtained by using clockwork as the motor power. Such an arrangement is very expensive and is unsatisfactory in several ways.

The drum shown in fig. 33 is either a hand-drum or an electric drum. The cast-iron base is supported on three fixed and one adjustable leg. The drum itself runs on hardened steel centers

[1] Phys. Psych. 3 ed. II 279.

held by two uprights bolted to the base. When the drum is to be turned by hand, a large wheel is placed on the axle as shown in the figure. With this weight the drum will run several minutes with

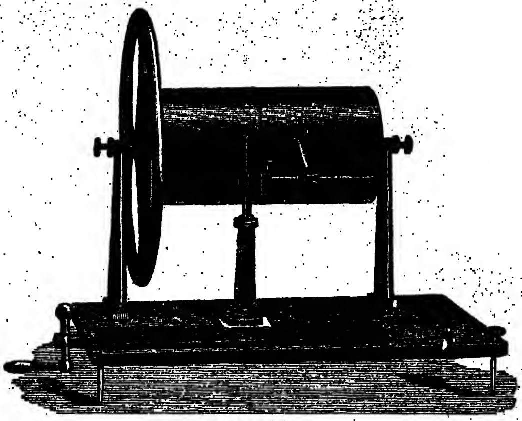


Fig. 83.

one impulse of the hand. When an electric motor is to be used, the wheel is removed and a pulley is placed on the axle. The motor is fastened to the base by a slide and bolt.

The carriage for the time-marker is mounted on rails planed like those of a lathe-rest. Rigidity is attained by the conical support for the rod.

STUDIES

FROM THE

Yale Psychological Laboratory

EDITED BY
EDWARD W. SCRIPTURE, Ph. D.
Instructor in Experimental Psychology

1896

VOL. IV

YALE UNIVERSITY
NEW HAVEN, CONN.

THE NEW ERA PRINTING COMPANY, LANCASTER, PA.

CONTENTS.

REACTION-TIME IN ABNORMAL CONDITIONS OF THE NERVOUS SYSTEM.

BY

ALFRED G. NADLER, M.D.

The object of the present research was to investigate the possible alterations in reaction-time and thought-time in diseased conditions of the nervous system. The experiments were performed upon individuals exhibiting symptoms diagnostic of one of four types of diseases. The subjects were patients applying at the University Clinic. The four types selected were neuritis, hysteria, locomotor ataxia and allied conditions, and alcoholism.

The experiments were performed on a Scripture pendulum-chronoscope, which consists of a pendulum, a pointer, a scale, a signal and a reaction-apparatus.[1] The pendulum is held at one side by a catch; when set free, it travels across the scale. As it passes the zero point it sets in motion and carries with it the pointer; the scale is divided into thousandths of a second, the pendulum and pointer being so arranged that one second elapses while the pointer travels from 0 to 1000. As it passes the zero point the pendulum springs a catch which gives the signal to the subject. This individual, all prepared, with a finger on the reaction button, presses the button in response to the signal. This locks the pointer against the scale at whatsoever point it happens to be. The experimenter has then only to read off the mark on the scale at which the pointer is set.

For simple reaction-time, the opening of a shutter on the signal board was the signal; for complex reaction-time red or white cards were indiscriminately inserted behind the shutter and the subject reacted only when the red card was seen.

The simple reaction consisted in this case psychologically of perception and volition, physiologically of the passage of a nervous impulse from the eye to the visual center in the brain, then to the arm center and downward to the muscles of the arm and hand. The complex reaction-time adds to this the two mental processes: discrimination between the

[1] SCRIPTURE, *Some new apparatus*, Stud. Yale Psych. Lab., 1895 III 98. The mean error of this instrument is two thousandths of a second; the mean variations of the records are therefore psychological quantities; see SCRIPTURE, New Psychology, 142, London, 1897.

colors and choice between movement and rest; the physiological side of these processes is unknown.

In classifying and arranging the results, the "median" was used[1] instead of the average as a basis of comparison or discussion. The median is the middle value in a set of numbers; for example, if there are 10 or 20 members, it is the average of the fifth and sixth, or the tenth and eleventh; if there are 11 or 15 numbers, it is the sixth or the eighth one.

LOCAL NEURITIS.

In this group are classed all those cases in which the nerves supplying the muscles of the forearm or hand were affected, causing a partial paralysis of either hand. It comprises neuroses of a local nature due either to trauma or toxines. In all cases, one or more branches of the brachial plexus or nerves were affected. At the seat of a local lesion of a peripheral nerve or a nerve whose branches supply the periphery, the nerve is usually inflamed, that is, swollen, infiltrated and reddened. The sheath alone may be diseased or the inflammation may affect also the internal portion, under which circumstances the infiltration is more extensive and surrounds the nerve bundles. The nerve fibres themselves may not be involved, but there is an increase of the nuclei in the sheath of SCHWANN. The myelin is fragmented, the nuclei of the internodal cells are swollen, and the axis cylinders present varicosities or undergo granular degeneration. The nerve fibres may be entirely destroyed and replaced by a fibrous connective tissue in which fat is deposited. In neuritis due to lead poisoning and in the more serious cases due to trauma, the changes met with in the nerves are somewhat different. This is termed parenchymatous neuritis and the changes resemble closely that described as secondary or WALLERIAN degeneration, which follows when a nerve is cut off from its center. There is segmentation in the myelin and breaking up of the axis cylinder, with proliferation of the nuclei of the sheath of SCHWANN and neurilemma. The changes may be limited to the medullary sheath, constituting what GOMBAULT has termed peri-axial neuritis. These neuritic changes are found in segments, the affected portions being separated by healthy parts; this is the so-called "segmental neuritis." In the musculo-spiral nerve, which is especially affected in lead poisoning, the parenchymatous and peri-axial neuritis are found together, the former generally being in the small branches going to

[1] SCRIPTURE, *On mean values for direct measurements*, Stud. Yale Psych. Lab., 1895 III 1.

the muscles, the latter in the main nerve trunk and larger branches. The symptoms in the following cases were pain along the arm and hand over the course of the nerve affected, several points of tenderness on the periphery, an inability to freely move the arm or forearm or hand or one or more fingers. Sometimes the flexor muscles were affected, more often the extensor. Some tactile sensation also was lost.

TABLE I.

Subject.	Disease.	S	d_S	C	d_C
W. B.	Neuritis due to injury	215	78	353	146
M. Y.	Neuritis	390	36	504	66
J. M.	"	379	16	557	34
J. W.	"	379	53	498	48
H. G.	"	314	91	442	163
L. M.	Neuritis, alcoholic	192	39	428	48
M. M.	Neuritis	407	35	525	39
J. W.	Neuritis, wrist drop	166	22	299	38
J. W.	After treatment	143	24	277	33
A. L.	Neuritis	294	61	478	87
A. L.	After partial treatment	185	14	487	47
J. S.	Neuritis, diseased arm	403	12	640	10
J. S.	Sound arm	256	20	423	12
C. W.	Neuritis, diseased arm	393	17	504	14
C. W.	Sound arm	243	14	392	5

Unit, thousandth of a second.
Number of records on each subject, 40.
S, simple reaction-time.
C, complex reaction-time.
d_S, d_C, mean variations for the individual subjects.

As would naturally be expected from such diseased conditions, the reaction-time is materially lengthened. The increase is undoubtedly due to the local lesion of the nerve. This is proven by the varying increases over the normal in the different subjects according to the extent or cause of the injury or the severity of the symptoms. It is also proven by the fact that the complex time is only so much longer than the simple reaction-time as exists ordinarily in normal conditions.

The mean variation, which is the index of regularity in the action of the patient's mind, is not greater than that found in healthy persons under the same conditions.

It was found that in patients with but one arm affected, the reaction-time was longer in the diseased arm than in the unaffected limb; in patients experimented upon during or after treatment the results improved with improved conditions.

Locomotor ataxia and multiple neuritis.

The diseases of this group are affections of the spinal cord due to degeneration or sclerosis of one or another tract or column.

Although the results are alike in many respects, there are sufficient differences to bring out the distinction between the two diseases.

Locomotor ataxia is an affection of the nervous system characterized clinically by incoördination with sensory and trophic disturbances and involvement of the special senses, particularly the eyes. Pathologically there is sclerosis of the posterior columns of the cord, foci of degeneration in the basal ganglia, and sometimes chronic degenerative changes in the cortex cerebri. The peripheral nerves also undergo degeneration.

Marie asserts that the primary change is a nutritional defect of the ganglion cells of the posterior root. In this disease, there is not loss of motor power, but incoördination. The motor, efferent fibres of the peripheral nerves are intact. In ordinary peripheral neuritis, both motor and sensory fibres are diseased. The ganglion cells of the posterior spinal ganglia are destroyed in tabes, but their axis cylinder prolongations in the cord undergo degeneration and atrophy; consequently a sclerosis occurs in the three ascending tracts, namely, Lissauer's tract, the postero-external column and Goll's column.

In multiple neuritis the lesions and pathological conditions are practically the same as in localized neuritis, with, of course, extension to larger areas and the involvement of more nerves and portions of the cerebral and spinal ganglia.

The symptoms of locomotor ataxia are manifested mainly by a lack of coördination. The lower extremities are principally affected, causing the characteristic ataxic gait. In advanced cases the arms and hands are involved, producing numbness or tingling in the fingers.

Table II.

Subject.	Disease.	S	d_S	C	d_C
C. M.	Locomotor ataxia . . .	393	9	869	24
F. H.	" "	374	9	728	39
F. N.	" "	392	6	793	15
G. R.	" "	385	6	767	12
J. K.	Multiple neuritis	421	14	864	16
G. B.	" "	412	19	794	42
S. P.	" "	414	72	756	132

Unit, thousandth of a second.
Number of records on each subject, 40.
S, simple reaction-time.
C, complex reaction-time.
d_S, d_C, mean variations for the individual subjects.

In multiple neuritis, since the motor nerves are peculiarly affected, the symptoms are mainly those of paraplegia. The extensor muscles are affected more than the flexors, causing thereby wrist-drop and foot-drop and the peculiar steppage gait.

The simple reaction-times in these cases were markedly long, longer in those affected with multiple neuritis than in the tabetic patients. The thought-times were distinctively long also, but more so in the group of locomotor ataxia patients. The mean variations were comparatively small in all the series except in one subject.

Do these results agree with the symptoms and pathological conditions? And are they such as one might reasonably expect? I think we can answer in the affirmative.

In the first place let us compare the simple reaction-times. The results are longer in the multiple neuritis cases in this set of experiments. This is surely in accordance with expectation. The observer has simply to react and, the motor nerves being affected, the outward current travels more slowly; the result is a longer reaction-time. For tabetic patients the disturbance in coördination would also cause some lengthening beyond the normal time.

In regard to the complex reaction-time this difference between the two classes would appear scarcely sufficient to affect the complicated process.

The astonishing regularity of the simple reactions in locomotor ataxia, as shown by the smallness of the mean variations, remains an inexplicable fact.

ALCOHOLISM.

The patients which I have classified under the title alcoholism, for want of a better name, were men on the verge of delirium tremens.

They were men who had been on a "bout" for a varying number of days and appeared for treatment when on the border lines of consciousness. The condition is such as is seen by every one almost any day on the streets of a large city. It is a stage beyond drunkenness.

The patients are men who are immuned to alcohol and have drunk enormous quantities during their lives. They no longer become intoxicated according to the popular idea of that term. Their tissues and organs are probably saturated with the toxine. They are accustomed to drink gin and whiskey. Their condition would be, perhaps, best described as that due to systematic intoxication.

When they come for treatment their minds are clear and active; they are acutely anxious. Being aware of the condition in which they are, they are fearful lest it become worse. They cannot sleep and are ut-

terly worn out; tremors shake their frames. The walk is shaky and weak, but not staggering. Sleep is their necessity and without medical interference sleep will not come. Unless their need is fulfilled the condition becomes rapidly worse and the patient is soon in the throes of delirium tremens.

The pathological condition in this affection is not accurately known, but, reasoning by analogy, one cannot be far wrong in the following description: There is in the brain a shrinking of the substance with narrow, flattened and shrunken convolutions, and serous effusion in the ventricles and subarachnoid space. Some of the vessels have degenerated and blood has oozed into the brain substance. The nerve cells and fibres are wasted throughout their course. In the cord there is increased vascularity, especially in the posterior columns. The changes in the nerve fibres are those of sclerosis or fatty degeneration.

TABLE III.

Subject.	Disease.	S	d_S	C	d_C
J. M.	Alcoholism	156	15	479	28
P. M.	"	174	30	434	60
J. L.	"	164	6	464	20
F. W.	"	161	6	469	11
I. M.	"	163	9	528	18
J. B.	"	161	8	506	12
A. P.	"	168	9	453	20
P. M.	"	155	6	443	27
P. M.	"	169	9	398	7
F. S.	"	160	11	416	23
G. W.	"	195	16	507	32
J. W.	"	184	13	394	15
T. L.	"	173	13	397	8
L. M.	"	178	19	424	29
T. H.	"	163	20	415	72
T. H.	After treatment	131	5	394	22
J. H.	Alcoholism	157	8	499	10
J. H.	Partially cured	156	6	397	9
M. M.	Alcoholism	164	18	421	44
M. M.	Cured of attack	160	13	397	11

Unit, thousandth of a second.
Number of records on each subject, 40.
S, simple reaction-time.
C, complex reaction-time.
d_S, d_C, mean variations for the individual subjects.

In this group, strange to relate, the simple reaction-times are considerably shorter than in any series of experiments performed on healthy persons at the Yale laboratory. The complex times, however, are longer, that

is to say, the differences between the simple reaction-times and the complex times are larger than for the normal person. The mean variations are comparatively small in the first series, and in the latter they appear to depend upon the personal attributes of the observer.

In the experiments made upon the same individuals after treatment, the results showed a decrease in the reaction-times throughout, making the simple reaction-time less than in the normal and the complex time about normal. These results appear to show that the effect of the alcoholic toxine upon the individual is to heighten the power to perform simple regular movements, but that where a judgment is needed, the individual is at a disadvantage.

Hysteria.

To better understand the peculiar results of the experiments on hysterical subjects it may be well to begin with a brief characterization of the disease.

"Hysteria is a functional disorder of the nervous system, associated with excitability and a want of will power. It is manifested by uncontrollable nervous paroxysm or crises, and intermediate states of perverted nerve function. * * * The symptoms vary from mere exhibitions of excitability provoked by slight causes to prolonged and frequent convulsive attacks. Paroxysms of uncontrollable laughter or crying, without apparent reason, explosions of anger or terror upon the slightest provocation, headache, sleeplessness, attacks of trembling, flushing, chilliness, choking sensations, and, above all, unreasonable actions or complaints designed to impress the spectator with the importance or wonderful character of the ailments. All sorts of vagaries resulting from a perverted imagination assist in making up a truly kaleidoscopic clinical exhibition.[1] The symptoms vary from day to day. Upon being questioned regarding their trouble, the patients reply that "they are so very nervous." That statement covers the ground. In the majority of cases, the patient has exaggerated a slight trouble until it has assumed tremendous proportions in her eyes, and once having fallen into the habit she is with difficulty taught its error.

In this group, the reaction-times were very erratic, that being the most noticeable feature. The median for the simple reaction-time is almost normal, but the mean variation is extremely large. The complex time is increased greatly above the normal and here again the mean variation is greatly enlarged. The cause lies probably in the difficulty with which

[1] Byford, Manual of Gynecology, 137, Philadelphia, 1895.

the observers concentrated their attention. In some cases it appeared as if the patients had forgotten what they were attempting to do. Suddenly they would recollect and react, the time, of course, being greatly prolonged. This was especially true of the complex time. Or perhaps the patient would not be positive at first and would require a second thought to assure herself that the signal was read correctly.

The experimental results are given in the following table:

TABLE IV.

Subject.	Disease.	S	d_S	C	d_C
H. G.	Hysteria	308	91	399	197
E. S.	"	235	54	742	93
F. F.	"	287	77	779	123
H. A.	"	198	2[illegible]	764	96
W. F.	"	186	17	599	51
J. W.	"	184	23	612	34
P. A.	"	198	31	744	68
C. A.	"	193	20	802	73
M. M.	"	187	26	749	91
P. H.	"	187	21	736	108
M. S.	"	483	185	641	167
D. A.	"	164	66	!	!

Unit, thousandth of a second.
Number of records on each subject, 40.
S, simple reaction-time.
C, complex reaction-time.
d_S, d_C, mean variations for the individual subjects.

It was found impossible to secure any records of complex time for D. A., as she could not refrain from reacting to every fall of the shutter, regardless of the color it showed.

SUMMARY.[1]

In order to compare the results for the different diseases the general average must be computed for each disease. The mean variation for each observer serves for this purpose the same function as the mean error of a set of physical measurements. Let $d_1, d_2, \cdots, d_k$ be the mean variations for the various individuals whose averages are respectively $a_1, a_2, \cdots, a_k$. Since each average was obtained from n experiments, the mean variations for each of the averages will be

$$D_1 = \frac{d_1}{\sqrt{n}},\quad D_2 = \frac{d_2}{\sqrt{n}}, \cdots, D_k = \frac{d_k}{\sqrt{n}}.$$

[1] By the editor.

The weights of the averages are therefore

$$p_1 = \frac{1}{D_1^2},\ p_2 = \frac{1}{D_2^2}, \dots, p_k = \frac{1}{D_k^2}.$$

The final average is

$$A = \frac{p_1 a_1 + p_2 a_2 + \cdots + p_k a_k}{p_1 + p_2 + \cdots + p_k}.$$

Since the number of experiments was the same in every case, the value n is constant and the same result for A is obtained by using

$$p_1 = \frac{1}{d_1^2},\ p_2 = \frac{1}{d_2^2}, \dots,\ p_k = \frac{1}{d_k^2}$$

instead of the formulas previously given. The final average for each disease is calculated in this way.

If we consider the mean variation for an individual as a measure of his uncertainty of mental action, we can inquire for the average uncertainty of the group, which for k individuals will be

$$U = \frac{d_1 + d_2 + \cdots + d_k}{k}.$$

The average mental uncertainty is calculated for each disease.

Lastly, to complete the picture of the disease it is necessary to indicate how the individuals differ from each other in their averages. This is done by computing the statistical mean variation.

Let A be the average for the whole group whose individual values, or averages, are a_1, a_2, $\cdots$, a_k; then the individuals vary from the group-average by $v_1 = A - a_1$, $v_2 = A - a_2$, $\cdots$, $v_k = A - a_k$. The average variation of the individuals of the group will be

$$V = \frac{v_1 + v_2 + \cdots + v_k}{k}.$$

This figure indicates the homogeneity of the group, and thus gives a characteristic of the uniformity of the disease in this particular property.

The calculations have been performed and verified with the greatest care, CRELLE's[1] and BARLOW's[2] tables being used wherever possible.

---

[1] CRELLE, Rechentafeln, Berlin, 1857.

[2] BARLOW, New Mathematical Tables, London, 1814.

In order to have a comparison with normal individuals I have added computations from the records made on 19 college students, each record consisting of ten experiments.

Condition.	*S*	*U*	*V*	*C*	*U'*	*V'*	*B*	*k*
Local neuritis	360	42	67	570	63	135	210	11
Multiple neuritis	418	5	4	848	63	54	430	3
Locomotor ataxia	387	8	7	786	23	42	399	4
Alcoholism	163	13	7	440	26	48	277	17
Hysteria	192	53	51	671	100	96	479	12
Normal	179	29	31	349	58	58	170	19

S, simple reaction-time.
C, complex reaction-time.
U, *U'*, averages of the individual mean variations.
V, *V'*, average departures of the individuals from the typical averages *S* and *C*.
B, difference between *C* and *S*.
k, number of individuals.

The following conclusions seem to be justified by the table:

1. Alcoholism shortens the simple reaction-time, hysteria leaves it unchanged and local neuritis, multiple neuritis and locomotor ataxia lengthen it. (Column *S*.)

2. Local neuritis slightly lengthens the additional mental processes involved in complex reaction-time, alcoholism lengthens them considerably, while locomotor ataxia, multiple neuritis, and hysteria double and triple the normal time. (Column *B*.)

3. The individual's regularity is much greater than the normal in locomotor ataxia and alcoholism, and much less than normal in the other diseases. The irregularity is specially marked in hysteria for the higher mental processes. (Columns *U*, *U'*.)

4. Subjects with multiple neuritis, locomotor ataxia and alcoholism are much more distinctly marked off in respect to these tests than normal individuals. The close agreement of the seventeen alcoholic patients in regard to simple reaction-time is very remarkable. (Columns *V*, *V'*.)

Summing up by diseases, I believe it justifiable to say that in the two respects of simple and complex reaction-time they are characterized as follows:

1. Local neuritis: a poorly defined group with long simple reaction-time and great irregularity.

2. Multiple neuritis: a very closely defined group with very long time for both simple reactions and more complicated mental processes; also considerable irregularity in the individual.

3. Locomotor ataxia: a very closely defined group, slow in reaction

and in the higher processes, but astonishingly free from individual irregularities.

4. Alcoholism: a very closely defined group with accelerated reaction-time and not generally retarded complex time, remarkably free from irregularity.

5. Hysteria: an indefinite group, with normal simple reaction-time but greatly lengthened complex time, exhibiting extreme irregularity.

RESEARCHES ON REACTION-TIME.

BY

E. W. SCRIPTURE.

From time to time various problems present themselves in connection with the study of the time of mental processes. It has been my custom to assign some of these problems to special students. The work is done under my personal direction, and, almost without exception, I serve as the subject or the experimenter.

INFLUENCE OF A CONSTANT ELECTRIC CURRENT THROUGH THE HEAD.

(JOHN L. BURNHAM.)

The city supply (110 volts, direct) was used as the source of current. One wire was led to the binding post of a graphite resistance which regulated the amount of current. This graphite regulator comprised a plate of ground glass sliding in a grooved frame. Lines of different thickness were drawn with a lead pencil on the glass. By moving the glass any one of these lines could be placed under the springs connected with the two binding posts, whereby a resistance of any desired amount could be introduced into the circuit.

The current was made to pass through an EDELMANN milliampère-meter indicating directly the quantity of current used. The poles were two sponge electrodes. A commutator permitted the change in direction of the current and a liquid resistance rendered it possible to gradually apply or remove the current without shock, and without the knowledge of the subject.

In all the experiments where electricity was used, the records were so divided that the experiments without electricity (with the electrodes still in place but no current on) were interposed between two sets of the records of electricity, or else the start and finish would be made without electricity while the current was used for the middle records. Thus any lingering effect of the stimulus or any mental disturbance from the electrodes was neutralized. These experiments were conducted during the month of February, 1896.

The tests for the effect of the current were: simple reaction-time and complex reaction-time. The shutter of the pendulum chronoscope ex-

posed a colored disc and the subjected reacted by pressure on the knob at the back of the instrument[1]. For complex reaction-time one of two colors was exposed, the subject being required to react to one and not to the other.

TABLE I.

O	*F*	*ma*	*S*	*d*	S_e	*d*	*n*	*C*	*d*	C_e	*d*	*n*
S. head	1	1.0	143	11	143	15	7					
" "	3	1.0	146	15	137	7	7					
" "	3	1.6						281	49	274	45	10
" "	3	4.0								239	28	8
B., "	1	1.0	194	52	153	34	10					
" "	3	1.0	143	23	135	9	7					
" "	5	0.2	143	15	129	6	10	312	56	270	60	5
" "	13	1.8	143	18	129	15	10	260	9	256	25	5
" "	15	0.3	127	19	121	10	10					
Sm., "	5	0.2	132	12	121	18	10					
T., "	2	0.3	140	8	140	9	10					
" "	12	1.3	186	23	161	21	10	320	34	235	41	5
" "	13	1.0	149	10	139	14	10	287	29	304	53	5
D. "	1	0.5	136	29	157	23	5	264	66	272	60	5
" "	5	1.2	136	11	128	11	5	290	36	249	54	5
" "	5	7.0	142	10	117	5	5	279	19	275	27	5
" "	12	0.3	144	27	150	14	5	330	54	323	36	5

Unit, thousandth of a second.
O, subject of experiment.
F, date in February, 1896.
ma, milliampères.
S, simple reaction-time without electricity.
S_e, simple reaction-time with electricity.
C, complex reaction-time without electricity.
C_e, complex reaction-time with electricity.
d, mean variation.
n, number of experiments in each set.

A glance at the above table will show an almost universal quickening of both the simple and complex times under the stimulus of the electric current. A general quantitative statement of the amount is not possible, owing to variations in the conditions of different experiments.

It will be noticed that in the table there are some negative results with the moderate currents. Again, the effect of the electric current varies greatly on different people and seems also to affect the same person to different degrees at different times. For example, subject D., who took 7 milliampères on February 5, with no hesitation, felt that he was being

[1] SCRIPTURE, *Some new apparatus*, Stud. Yale Psych. Lab., 1895 III 98.

hurt with less than half that amount a week later and was willing to perform the experiment with only 0.3 of one milliampère.

However, in viewing all the results, the few conflicting records are lost sight of and the conclusion seems to be clearly indicated that the electric current shortens both the simple reaction-time and the complex time. Beyond this, by the introspective testimony of several of the subjects, there was a decided feeling of refreshment after the application of the electric current, the person feeling better at the close than at the beginning of the experiment. In only one case, where a high current of 9 milliampères was used (no reliable records could be taken), vertigo, double vision and the peculiar metallic taste were noticed by the subject.

From these experiments we might perhaps conclude that the brain was directly stimulated and quickened in its processes. Nevertheless, in consideration of the unusual character of the case, we prefer at the present time not to go beyond the statement that for some unknown cause the reactions were quicker with the electrical current than without it.

Influence of fatigue.

The term "fatigue" is used in different senses. It may mean the condition of body and mind resulting from the presence of certain toxic products in the blood. This kind of fatigue may arise from the activity of the organism itself in mental or bodily work, or it may arise by the transfusion of blood from an already fatigued organism.[1]

Fatigue is also used to mean a direct deterioration in the functional activity of the whole organism or of some part of it. When the just perceptible difference is being repeatedly measured in succession under the most favorable circumstances, its size may change with the progress of the series of records. A change toward a decreased difference, or finer sensibility, is called "a change due to practice;" a change toward an increased difference, or lesser sensibility, is called "a change due to fatigue."

Likewise a lengthening of the tap-time or reaction-time in a steadily repeated series—all other conditions remaining the same—would be called "a change due to fatigue." It would seem better to name it directly the "fatigue in tap-time, in reaction-time, etc.," because such expressions as "due to fatigue," "due to practice," etc., convey the impression of an explanation where none is present.

"Fatigue" is also used to indicate a complexity of sensations usually but not necessarily connected with toxic or functional fatigue.

[1] Mosso, *Ueber die Gesetze der Ermüdung*, Arch. f. Physiol. (Du Bois-Reymond), 1890, 89.

There are thus three different phenomena denoted by the term "fatigue:" (1) a chemical change in the constitution of parts of the organism; (2) a diminution in functional activity; (3) a group of sensations. These three are usually connected. Thus the connection of the amount of work done (and the consequently available energy for further work) with the change in the nerve cells has been demonstrated by HODGE.[1] The connection between the amount of work done and the sensation of fatigue is familiar to every one. The connection between the sensation of fatigue and the actual exhaustion of the organism is not always maintained; thus, neurasthenia is treated by COWLES[2] as an exhausted condition of the nervous system accompanied by anæsthesia for fatigue.

In the following investigations on reaction-time no regard is paid to the sensation of fatigue; the problems are: (1) What are the characteristics of special fatigue in reaction-time? (2) Are these characteristics observable also in cases of general fatigue?

SPECIAL FATIGUE IN REACTION-TIME.

(A. E. VON TOBEL.)

In several different measurements closely related to those of reaction-time, e. g., tap-time[3], accommodation-time[4], fatigue has been observed. This fatigue may be a fatigue in length whereby the average time becomes longer, or it may be a fatigue in regularity whereby the mean variation becomes larger. The two kinds of fatigue do not follow the same course; in the experiments of both BLISS and MOORE the average time of tapping is lengthened long before any noteworthy change appears in the mean variation.

In the usual experiments on reaction-time an interval of about 10^s rest follows each experiment and longer intervals follow groups of 10 or 20 experiments. In this way fatigue is usually avoided. If, however, the experiments are repeated in close succession there is no possibility of

[1] HODGE, *A microscopical study of the nerve cell during electrical stimulation*, Journal of Morphology, 1894 IX 449.

[2] COWLES, Neurasthenia and its Mental Symptoms, Shattuck Lecture, Boston, 1891.

[3] DRESSLAR, *Some influences which affect the rapidity of voluntary movements*, Am. Jour. Psych., 1891 IV 514.

BLISS, *Investigations in reaction-time and attention*, Stud. Yale Psych. Lab., 1893 I 45–49.

MOORE, *Studies of fatigue*, Stud. Yale Psych. Lab., 1895 III 92.

[4] MOORE, *Studies of fatigue*, Stud. Yale Psych. Lab., 1895 III 87.

rest. Series of such experiments have been made by PATRIZI.[1] The stimulus occurred at intervals of 2ˢ and the subject was to react as quickly as possible each time. The same characteristics were found as in tapping and accommodation, namely, a lengthening of the average time and an increase in the mean variation.

It was determined to carry the problem further, and, in reference to certain observations on methods of inducing hypnotic sleep, to determine in what particular part of the process the fatigue arose. It was proposed, therefore, to investigate the fatigue in the case of repeated flashes of light, and to determine whether it is due to the muscles of accommodation and convergence, to attention or to both muscles and attention.

The flash was produced by a small GEISSLER tube, connected with a spark coil in the adjoining room. The primary circuit of the coil passed through a modified WUNDT contact-apparatus.[2] This was so arranged that a revolving arm made contact at definite points with brass blocks in such a way as to illuminate the tube at regular intervals.

The tube was placed on a table in the isolated room and the subject was seated before it. The room is so constructed that neither light nor sound can enter from the outside.[3] The room was supplied with fresh air by a blower, operated from the floor below.

A telegraph key in the isolated room was arranged in a circuit with a DEPREZ-marker which wrote on the drum of a kymograph. A subject was told to press the key in response to each flash; nothing was said about removing the pressure. The pressing of the key caused a downward movement in the point of the marker and the release of the key a movement back to the original position. We thus have two mental phenomena recorded: the first is the reaction-time from the moment of the flash to the pressure on the key; the second is the length of time during which the subject chooses to hold the key down.

The experiments were continued during a long interval. Records were taken for a number of times at the beginning and then for a number of times at the end. Mr. von Tobel, a college senior, was the subject of the experiments.

After a sufficient number of records had been taken, the drum was allowed to revolve without being moved axially; the reactions continued as before, but the records overlapped and were not regarded.

[1] PATRIZI, *La graphique psychométrique de l'attention*, Archives ital. de biologie, 1894 XXII 187.

[2] WUNDT, Physiologische Psychologie, II 424, Leipzig, 1893.

[3] BLISS, *Investigations in reaction-time and attention*, Stud. Yale Psych. Lab., 1893 I 2.

After the desired interval the drum was again moved axially and the records were separated. The reaction-times were longer and very irregular. The time of holding was enormously lengthened. As nothing had been said to the subject concerning releasing the key, it was done semi-consciously. The time of holding was sometimes so long that the subject was apparently not fully awake. In fact, various statements of the subject showed that on some occasions he had fallen into a half-dazed condition resembling the first stage of passage toward hypnotic sleep.

The further details of the apparatus were the usual ones. The drum was timed by the JACQUET chronometer. The records were read in hundredths of a second; the next decimal arising in the averages was retained.

In the first series of experiments the room was kept dark. Both eyes were open and relaxed. The appearance of the flash caused both convergence and accommodation. In the next series one eye was bandaged in order to reduce the convergence; it is an easily demonstrable fact that the closed eye only partially performs the movement necessary for convergence. In a third series one eye is bandaged as before, but a light is turned on in the room; as the subject looks constantly at the tube all the time, the condition of accommodation is a steady one. In all three cases the mental condition known as "attention" is present; in the third there is no noticeable muscular effort in the eyes; in the second there is at each flash a definite change of accommodation with imperfect convergence and in the first there are definite acts of both accommodation and convergence.

The first record was as follows: No light in the room; both eyes open; flashes once in two seconds—

	Reaction-time.	Mean Variation.	Holding-time.
At start	195^{σ}	11^{σ}	319^{σ}
After 5^{m}	300	43	753
Fatigue	105	32	434

Here we see that after five minutes, or about 150 flashes, the time of reaction was increased about 60%, the time of holding down the key was lengthened about 130%, and the irregularity was four times as great. The subject states: "During the experiment I felt a strong sense of contraction between the eyes. I also found that it required great effort to keep the attention fixed on the tube. It seemed to float around and move upward."

The next record was taken under exactly the same conditions, but was continued for 10^m—

	Reaction-time.	Mean Variation.	Holding-time.
At start	224σ	10σ	163σ
After 10^m	304	32	837
Fatigue	80	22	674

The reaction-time increased about 35%, the holding-time over 400%, and the irregularity 300%. "The bodily effects were much the same as before, only more intense. Tears flowed freely from the eyes, the feeling of contraction between the eyes became almost painful and there was a sort of general lassitude and disinclination to move."

For the third record all conditions were the same as before, except that one eye was bandaged. In this set a series of records was taken after an interval of 15 minutes also. The results were as follows—

	Reaction-time.	Mean Variation.	Holding-time.
At start	241σ	13σ	404σ
After 5^m	328	33	758
" 10^m	297	25	859
" 15^m	337	34	593
Fatigue at 5^m	87	20	354
" " 10^m	56	12	455
" " 15^m	96	21	189

"In this series I felt much greater effects than in any of the others and seemed to approach nearer a hypnotic state. There was a general feeling of fatigue all over the body, accompanied by a slight stiffness of the joints, also a feeling of floating off in the air or of dropping off to sleep."

The last set of experiments was taken with only one eye open and with a light in the room, thus eliminating the acts of accommodation and (practically) of convergence. The results were as follows:

	Reaction-time.	Mean Variation.	Holding-time.
At start	267σ	24σ	176σ
After 5^m	278	10	184
" 10^m	296	10	652
Fatigue at 5^m	11	–14	8
" " 10^m	29	–14	476

The results apparently show that fatigue of attention alone produces —at least within the first 10^m—very little lengthening of reaction-time. The increased regularity—"practice"—continues. The ten-

dency of the subject to finally "fall asleep" over his work is shown in the greatly increased holding-time in the last case.

A comparison of all the results seems to indicate the following conclusions:

1. The fatigue in reaction-time increases with the complexity of the adjustments required for perceiving the stimulus. There is least fatigue when only an effort of attention is involved, more when the act of accommodation is added and still more when the act of convergence is also added.

2. The tendency of the subject to fall into a condition of daze, as indicated by the holding-time, depends on the fact of repetition of the stimulus (fatigue of attention?) as well as on the fatigue from the adjustments.

The application of these results to the common methods of hypnotizing requires no remark.

General fatigue and reaction-time.

(John L. Burnham.)

Experiments on simple and complex reaction-time were made with the chronoscope in the manner previously described (p. 12). The morning records were made at 8:30, just before the duties of the day began, i. e., just after breakfast and before the first recitation in college. The afternoon records were made at 5:30, after the day's work had closed with a two hours session of laboratory work. The results of several series of experiments are given in Table II.

Table II.

	Morning.						Afternoon.						Difference.	
Subject.	*S*	*d*	*n*	*C*	*d*	*n*	*S*	*d*	*n*	*C*	*d*	*n*	*S*	*C*
Smith	119	10	60	263	38	60	127	16	60	309	34	60	8	46
v. Tobel	146	16	20	281	43	20	149	10	20	281	29	20	3	0
Burnham	128	13	80	256	29	80	141	15	80	278	27	80	13	22

Unit, thousandth of a second.
S, simple reaction-time.
C, complex reaction-time.
d, mean variation.

The bearing of this table of results is evident. The table shows an average lengthening of the afternoon records over those of the morning by 19^{σ} in simple and 24^{σ} in complex time. This is a loss of 15½% in one case and of 17% in the other.

It will be noticed that general fatigue has a very small influence on reaction-time as compared with special fatigue.

It may be interesting to add that at the end of these afternoon records a few records were sometimes taken under the electrical stimulus. This resulted in a shortening, but never enough to bring the time down to that of the morning. This seemed to indicate that the fatigue of the mind by a day's work is greater than can be overcome by the stimulating action of the electrical current, at least as used in these experiments.

Influence of tension on the reacting finger.

(John L. Burnham.)

The problem was suggested by the consideration that there might be some relation between the time of reaction and the energy of reaction.

The first set of experiments took the form of a constant tension applied to the reacting finger just before and during the experiment, whereby the reaction involved the moving of a weight. For this purpose a set of pulleys was arranged with a cord running over them. At one end the cord passed through a tape around the index finger of the reacting hand and at the other a 1000^g weight was attached. When the hand was put in position for reacting, the weight swung free. Thus there was a tension of 1000^g on the finger at the start and the whole mass must be raised by the finger as it pushed the key in reacting.

The first three records were taken on February 15 and 19, 1896. The results were so unexpected in various ways that the experiments were repeated for the observer E. W. Scripture at a later date, April 29, 1897, with the results as shown in the last record of the table.

Table III.

	Light.					Sound.				
Subject.	*R*	*d*	R_k	*d*	*B*	*R*	*d*	R_k	*d*	*B*
J. B.	127	9	127	6	0	131	9	123	8	8
J. D.	120	28	107	6	13	108	8	101	7	7
E. W. S.	152	26	128	11	24	172	30	136	16	36
E. W. S.	127	12	110	10	17	132	9	122	8	10
Weighted mean	132	19	118	8	14	136	14	121	10	15

Unit, thousandth of a second.
R, reaction without weight.
R_k, reaction with weight.
B, shortening due to weight.

d, mean variation.
Each figure is the average for ten experiments.

The shortening of the time is evident. Another noteworthy fact is the increase in the regularity of the reactions as indicated by the decrease in the mean variations. When errors of the apparatus and method are eliminated, the mean variation is a mental quantity expressing the subject's definiteness of perception and response.[1] This definiteness makes up a large part of the vague group of phenomena which goes under the name of "attention."

The following conclusions seem justifiable:

1. Increased definiteness of the act to be performed shortens the time required to begin it. In the case of the experiments with sound the action of the weight lay mainly or entirely in forcing "attention" to the finger to be moved. This was distinctly felt by the subject. When the weight was removed, the subject noticed the increased difficulty of attending to the movement. The shortening in time was 8^σ in the case of sound.

2. Increased definiteness of the expectant image of the sensation shortens the time required for responding to it. In the experiments on sight the stimulus was just above the finger and any increased attention would include it also. It could be directly observed introspectively that the strain on the finger forced attention to the place just behind it where the signal was to appear. The decreased ease of attention when the weight was removed was noticed here also.

3. The reaction-time decreases as the mental tension increases. This follows from the preceding conclusions. It is still more strongly brought out by the following facts:

a. Reactions with the pendulum chronoscope are always quicker than with other methods. This can be seen by comparing these figures with those obtained (p. 17) by use of the graphic method and the isolated room. This fact has been repeatedly noticed on various persons. An example of the short time required is seen in the average of 179^σ for 19 students (p. 10). A similar statement is true of GILBERT's results with his reaction-board.[2] The explanation is not hard to find. When the subject is placed in a quiet room away from all excitement,

[1] This view, definitely advocated and explained in The New Psychology, London, 1897, has for several years been part of my regular teaching. It is implied in the calculations published by GILBERT in Stud. Yale Psych. Lab., 1894 II 77 etc., and by MOORE in the same, 1895 III 76. Definite explanations of the meanings and relations of what I have termed the "individual mean variation," and the "statistical mean variation" are given in the Zt. f. Psych. u. Physiol. d. Sinn., 1896 X 163; see also the summary to NADLER's article on p. 8 above.

[2] GILBERT, *Researches on the mental and physical development of school-children*, Stud. Yale Psych. Lab., 1894 II 78.

there is nothing for him to do but to sit at ease till the warning for work arrives, and he falls into a more or less comfortable or relaxed condition of mind and body which is decidedly contrasted with that experienced with the apparatus and experimenter at his very face. The tense condition of mind under such circumstances is very evident to every one who reacts at the chronoscope.

b. The shortening of the reaction-time becomes especially marked in reactions to sight. The presence of the sight-shutter just above the reacting finger is conducive to the strictest attention. The reactions to sound do not gain in a similar manner, and thus it frequently results that a subject's reaction to sight is shorter than that to sound.

Influence of the amount of effort.

(Gerry R. Holden.)

The experiments with the strain on the finger, reported in the preceding section, had been planned for the purpose of solving the problem of the influence of the amount of effort on the time required for reacting. The records proved from the start just the reverse of what was expected, and it soon became clear that the constant strain on the finger produced an increase in attention which entirely overbalanced any effect of the increased effort.

Experiments were now planned in which there was no strain on the finger before the reaction and in which the subject was placed in the isolated room utterly away from the apparatus. Both factors of the increased attention in the previous experiments were now eliminated.

The reaction-key was made from a double contact telegraph key by lengthening the rear arm of the lever. A cord was attached to the lever and weights could be hooked at the end. The back contact of the key supported the weight until the knob was pressed. Pressure on the knob broke the contact, and lifted the weight at the same moment.

The graphic method of recording by means of the multiple key was used.[1] Pressure on the multiple key in the experiment room closed a sounder circuit, broke the primary circuit of a spark coil and immediately closed it again. A spark was thus made on the time-line of the drum at the moment of sending the current through the sounder, which, with a correction for the latent time, gives the moment of the sound in the isolated room. The subject broke the same primary circuit and made a second spark on the time-line.

[1] Bliss, *Investigations in reaction-time and attention*, Stud. Yale Psych. Lab., 1893 I 10. The latest model of this key is described below among the new apparatus.

The subject's finger rested upon the key with no exertion and no tension of the muscles. Experiments were made at intervals of 15^s. Each experiment was preceded, as usual, by a warning. An interval of about 10^m (during which the ventilating blower drove fresh air into the room) was taken for rest after each set of 25 or 30 experiments. Smaller rest intervals occurred as the weight was changed. Practice and fatigue were compensated in the usual way by the order of the experiments.

Each set of records for any one weight was preceded by experiments (not recorded) with the same weight in order to produce in the mind of the subject a definite idea of the effort to be exerted.

TABLE IV.

	100^g			200^g			500^g			1000^g			1500^g		
	R	*d*	*n*	*R*	*d*	*n*	*R*	*d*	*n*	*R*	*d*	*n*	*R*	*d*	*n*
Holden	168	17	47	171	13	19	191	22	21	173	12	34	166	15	19
Scripture	179	12	14	232	2	2	218	35	9	260	45	7	203	19	15
Seashore	165	24	6	—	—	—	—	—	—	—	—	—	187	22	8

Unit, thousandth of a second.
R, reaction-time.
d, mean variation.
n, number of measurements.

The conclusion to be drawn is different from the one expected. No definite relation is to be found between the amount of effort and the time of reaction, the results being irregular and contradictory. Careful observation showed the source of the irregularity. The finger being in a passive condition, it was necessary for the muscles and joints to do considerable work before the movement began. Moreover, the soft tissues at the end of the finger would yield considerably before the key would move. Not only was time consequently lost, but the complicated adjustments, especially for the heavier weights, rendered the records irregular. Thus, although the method of obtaining the definite effort had been found, the method of recording the result was not adequate for the purpose for which the work was undertaken. The figures, however, prove one very important fact, namely, that the tension of the spring of the telegraph key alters the record for the reaction-time. Some definite standard tension must be adopted if results by different observers and on different occasions are to be comparable. The tension of 0 would appear to be the best for adoption. This is the case in the slide reaction key[1] and in a telegraph key adjusted so that the back contact rests in place with little or no tension of the spring.

[1] SCRIPTURE AND MOORE, *A new reaction-key and the time of voluntary movement*, Stud. Yale Psych. Lab., 1893 I 88.

The next step was to eliminate the effect of strain on the finger. This was done by having the subject always react with a key of no tension; the telegraph key was used in order not to introduce any further change. The finger necessarily remained passive, as the key responded to the slightest movement. The subject reacted in alternate sets with two degrees of voluntary effort. The degrees were defined as "light" and "strong;" the intention was to make the effort correspond somewhat to the extremes of o and the heaviest weight in the previous set, but no measurements were made on the actual energy of effort.

The results are given in Table V.

TABLE V.

Subject.	Light effort.			Strong effort.			
	R	*d*	*n*	*R*	*d*	*n*	*D*
Holden	158	10	26	143	8	27	15
Scripture	179	16	17	154	19	18	25
Seashore	168	15	9	137	21	6	31
Fisher	626	25	5	375	41	6	241

Unit, thousandth of a second.
R, reaction-time.
d, mean variation.
n, number of measurements.
D, decrease in *R* for strong as compared with light effort.

The figures for the colored janitor, Fisher, are interesting. Having been accustomed for several years to serve as subject in exercises and investigations, he is perfectly at home in the work and yet has no interest or concern in the experiment beyond carrying out the instructions; these facts make his record very reliable. His unusually long reaction-time has been observed for several years.

The problem has thus found a definite solution: the intensity of the effort affects the reaction-time, making it shorter for the greater intensity.

SIMPLE AND CORTICAL REACTION-TIME.

(HOWARD F. SMITH, M.D.)

The determination of the time of a motor response to a direct stimulation of the cerebal cortex and a comparison of this time with the simple reaction-time of the subject would apparently lead to certain conclusions concerning the relation between mental and cerebral processes. The attempt has been made in the following manner.

A cat was held quietly in the hands of an assistant. A double pointed platinum electrode was rested against the skin at a suitable point. A

touch key[1] was rested against the same member in such a way that a movement would break an electric circuit. The electrode was connected with the secondary coil of an inductorium; an interrupted current was sent through the primary coil. The inductorium was so connected with the chronoscope that the electrodes stimulated the skin as the index passed the zero point. The touch key was connected with the magnets that stop the index. Thus, when the pendulum was released, a moderately noticeable (but not painful) electric shock was given to the foot or the lip, and the consequent reaction by withdrawing the leg or raising the head broke the circuit of the touch key and made a record on the chronoscope.

The first experiments were made on a cat weighing nearly three kilograms. The stimulus was applied (1) to the right fore foot with the key against the elbow; (2) to the right hind foot, with the key pressed against the heel; (3) to the upper lip with the key on the top of the head. The results were (d, mean variation; n, number of experiments): right fore foot, 96^{σ} ($^{\sigma} = 0.001^{s}$, $d = 26^{\sigma}$, $n = 7$); right hind foot, 116^{σ} ($d = 38^{\sigma}$, $n = 4$); lip, 61^{σ} ($d = 9^{\sigma}$, $n = 7$).

The next experiments were made with a cat weighing four kilograms. The results were: right fore foot, 41^{σ} ($d = 2^{\sigma}$, $n = 3$); right hind foot, 62^{σ} ($d = 0$, $n = 4$); lip, 62^{σ} ($d = 8^{\sigma}$, $n = 5$).

With the second cat we proceeded to a determination of the cortical reaction-time by etherizing the animal in the usual way.

Before the operation was begun but after the etherization (surgical degree) had been effected, the experiments on sensory-motor reaction were again tried with the same intensity of stimulation. No response was received anywhere except from the ear, 57^{σ} ($d = 8^{\sigma}$, $n = 2$).

It is a curious fact that the muscle here involved, the *Retrahens aurem*, is one which man has practically lost the use of. When the temporal muscle was laid bare by the operation, it was found to respond, when stimulated directly, with a time of 63^{σ} ($d = 11^{\sigma}$, $n = 3$).

The cortex was then exposed by the usual surgical procedure. The motor centers were found by the electrode and the key was applied in such a manner as to record the movements. The movements produced, however, were not quite the same as those used for the sensory-motor reaction. The results were: supination of right fore leg, 184^{σ} ($d = 7^{\sigma}$, $n = 2$); advance of right hind leg, 161^{σ} ($d = 26^{\sigma}$, $n = 6$); raising of head, 33^{σ} ($d = 17^{\sigma}$, $n = 2$); elevation of right side of upper lip, 37^{σ} ($d = 6^{\sigma}$, $n = 6$); closing of right eye, 61^{σ} ($d = 11^{\sigma}$, $n = 3$).

We notice, first, the remarkably quick reaction of the cat, being as quick

[1] SCRIPTURE, *Some new apparatus*, Stud. Yale Psych. Lab., 1895 III 108.

as 41^σ for the right fore foot. This may be compared with that of 89^σ for a dog about twice as large as the cat[1]; it is far below the time for human beings, which rarely falls as low as 100^σ. We next notice that the second cat, though larger, was much the quicker in each kind of reaction. In both cases the hind foot was 20^σ slower than the fore foot. This is analogous to results obtained by CATTELL and DOLLEY for human beings.[2]

Etherization destroys the reactions, presumably by cutting off the sensory half. It seems, also, that it seriously affects the motor centres, as the cortical reaction for the hind leg was 100^σ longer even than the complete reaction before etherization. It would be difficult to draw any conclusion concerning the relative portion of the complete reaction-time, which is used by the cortical reaction. Even if we assume that the cortical time is one-half of the complete time (probably by far too great a proportion), we have $33^\sigma \times 2 = 66^\sigma$ for the head-movement corresponding to the lip stimulation with raising head, which yielded only 41^σ. The discrepancy is undoubtedly due to the retardation caused by the use of ether.

In conclusion we may point out the peculiar importance of such researches as these for physiological psychology. For experimental psychology as applied to man the simple reaction-time consists of a process of sensation (perception) and one of volition. For physiology the reaction consists in transmission of the irritation to the brain, various processes in the brain and transmission of an impulse to the muscles. What is the relation between the two sets of simultaneous phenomena? As an example of some of the problems that present themselves in this respect, we may mention that of the character of the "motor centers" of the cortex. Are they truly motor centers governing the muscles directly or are they, rather, sensory centers from which impulses proceed to motor centers at lower points in the brain? In terms of time are they connected with earlier or later processes in the reaction? We may hope some day to answer the question by experimental means.

Perhaps the most important bearing, however, of these experiments is to be found in the fact that, following WEYER's investigation, they show the possibility of applying some of the psychological methods to the study of animals. It is the firm belief of the editor of the Studies that a quantitative science of comparative psychology can be established by the proper development and modification of the methods of experimental psychology.

[1] WEYER, *Some experiments on the reaction-time of a dog*, Stud. Yale Psych. Lab., 1895 III 96.

[2] CATTELL AND DOLLEY, *On reaction-times and the velocity of the nervous impulse*, Memoirs of the U. S. Nat. Acad. of Sciences, 1896 VII 404; previously summarized in the Psych. Rev., 1894 I 159.

INFLUENCE OF THE RATE OF CHANGE UPON THE PERCEPTION OF DIFFERENCES IN PRESSURE AND WEIGHT.

BY

C. E. SEASHORE, PH.D.

Among those who have experimentally advanced our psychological knowledge of the effects of very slow rates of change in the stimulation of the senses are HEINZMANN[1], FRATSCHER[2], PREYER[3] and SEDGWICK[4]. More or less systematic investigations have been made on changes between the slowest perceptible and the instantaneous ones by PREYER[5], HALL and DONALDSON[6], HALL and MOTORA[7], SCRIPTURE[8], STERN[9] and STRATTON[10].

Research on this subject has demonstrated several general facts: (1) The tendency of sensation to vary with the rate of stimulation is not primarily a peculiarity of any particular sense, because it is determined by general mental factors which enter into the perception of weak stimuli of all the senses in a similar manner. (2) The main value of knowledge of the laws here obtained does not lie in the acquaintance with the functioning of the particular sense organs that they furnish, but rather in that

[1] HEINZMANN, *Ueber die Wirkung sehr allmäliger Aenderungen thermischer Reize auf die Empfindungsnerven*, Archiv f. d. ges. Physiol. (Pflüger), 1872 VI 222.

[2] FRATSCHER, *Ueber continuirliche und langsame Nervenreizung*, Jenaische Zeitschrift f. Naturwissenschaft, 1875 IX (n. F. II) 130.

[3] PREYER, *Die Empfindung als Function der Reizänderung*, Zt. f. Psych. u. Physiol. der Sinn., 1894 VII 241.

[4] SEDGWICK, *On the variation of reflex excitability in the frog induced by changes of temperature*, Stud. from the Biol. Lab., Johns Hopkins Univ., 1882, 385.

[5] PREYER, *Die Grenzen der Tonwahrnehmung*, Jena 1876.

[6] HALL AND DONALDSON, *Motor sensations on the skin*, Mind, 1885 X 557.

[7] HALL AND MOTORA, *Dermal sensitiveness to gradual pressure changes*, Am. Jour. Psych., 1887 I 72.

[8] SCRIPTURE, *On the method of minimum variation*, Am. Jour. Psych., 1892 IV 577; *Ueber die Aenderungsempfindlichkeit*, Zt. f. Psych. u. Physiol. d. Sinn., 1893 VI 472.

[9] STERN, *Die Wahrnehmung von Helligkeitsveränderungen*, Zt. f. Psych. u. Physiol. d. Sinn., 1894 VII 249 and 395; *Die Wahrnehmung von Bewegungen vermittelst des Auges*, same volume p. 321, and *Die Wahrnehmung von Tonveränderungen*, same, 1896 XI 1.

[10] STRATTON, *Ueber die Wahrnehmung von Drückänderungen bei verschiedenen Geschwindigkeiten*, Phil. Stud., 1896 XII 525.

they become accessory means by which we may investigate the involved central conditions of sensational, emotional and voluntary reaction. (3) There are probably three stages of this time influence for all senses. (a) The threshold for the preception of instantaneous change is generally lower than the threshold for any gradual change. (b) A gradual change may be so slow that it cannot be perceived in any period during which it may be studied, even though the compared stimulus may be raised to several times the intensity of the standard and in some cases produce fatal results. (c) The variation of sensitiveness in the region between these two extremes of change depends upon several complex central and peripheral conditions with reference to which it must be defined.

The present report is upon experiments in two different senses, pressure and muscle sense, in which gradual changes are compared with each other and with instantaneous change. The investigation was in progress in the Yale Psychological Laboratory from October, 1895, to February, 1897.

I. Effect of the rate of change upon the perception of increase in pressure.

The object of this first series of experiments is to determine the law of sensitiveness to increase in pressure when the increase is made at various representative rates of gradual change. The problem requires the following experimental conditions: (1) an initial, standard pressure over a definite area; (2) a uniform increase in this at several desired rates without any other disturbance of the original pressure; and (3) the means of varying the rate and amount of increase. After considerable preliminary work I found that these conditions were best fulfilled by a hydrostatic balance. The one used is constructed on the principle that a solid body, gradually immersed in a liquid, loses weight in proportion to the displacement of the liquid. It will be described in parts for convenient reference in the successive series of experiments.

Apparatus A.

1. The graduated tube. This consists essentially of a vertical glass tube, continued at the lower end by a U-shaped metal tube which is terminated by metal nozzles. The vertical tube has an inside diameter of 42^{mm} and is 555^{mm} long. The curved tube has an inside diameter of 25^{mm} and the radius of its curvature is 120^{mm}. There is an outlet at the lowest point of this tube through which the water may be conducted into

an escape tube by opening a pinch cock. The free end of the U-tube is adjusted for the insertion of nozzles to regulate the stream of water which shall pass. These are interchangeable brass cylinders inserted in the lower end of a rubber tube which leads from a reservoir of water. In the upper part they have an inside diameter of 6^{mm}, but through the lower end they have a smaller bore; the five here used vary in a series according to the standard drill gauge numbers: 60, 45, 30, 15 and 1 with diameters of 1.0^{mm}, 2.1^{mm}, 3.3^{mm}, 4.6^{mm} and 5.8^{mm} respectively. Thus five different rates of flow may be obtained by using successive nozzles. The purpose of the U-tube is to break and quiet the stream. The straight tube carries a graduated scale of heights.

2. The balance. A very delicate balance is constructed of a steel rod, diameter 2^{mm}, and length 410^{mm}, with the fulcrum at the middle. It is supported on knife-edge bearings and braced by a diamond shaped framework of fine steel wire. Light hooks are inserted at the two extremities to serve as means for the attachment of parts to be balanced.

3. The float. This is a metal tube suspended from one end of the balance beam inside of the graduated tube. It causes a displacement in the liquid as it is gradually immersed. It is smooth and uniform, in this series 8.1^{mm} in diameter and 450^{mm} long and heavy enough to retain a steady vertical position in water. Its bottom ends in a tapering hard rubber point which reduces the friction and upward pressure of the stream.

4. Stimulus rod. The float is counterbalanced on the other end of the balance by a similar metal tube which carries the pressure point on its lower end. A tube is chosen because it gives rigidity to the pressure point; it may also serve as a receptacle for weights. The point is a hard rubber cylinder, of 5^{mm} diameter, whose edges are not rounded off but dulled by a light buffing.

5. The graduated scale. Readings of the pressure are made on a millimeter scale attached to the graduated tube. The zero point of the scale is at the surface of the water when the balance is in a horizontal position and the lower end of the float is immersed to a point just above the tapering end. Since the diameter of the float and the specific gravity of the water are known, the readings of the height of the column of water in millimeters are readily converted into grams of pressure as exerted by the pressure point.

6. The guide lever. The float end of the balance may be fixed rigidly at the point of equilibrium by means of a spring lever. The place to be stimulated can be brought within a definite distance of the pressure point. Releasing the lever releases the balance which transfers the standard

weight to the point pressed at a definite time and with a regulated momentum.

7. The inlet and outlet clamps. Ordinary pinch clamps are used for these purposes.

In order to test the rate of flow through a nozzle it is necessary to apply some time-measuring instrument to the apparatus. An electric key is fitted up which makes the circuit the moment the water begins to flow. It consists of one of the above pinch clamps furnished with an adjustable make-contact.

8. The fountain. The water reservoir is placed three meters above the outlet in order to secure an approximately constant flow even when there is some difference between the levels at the two extremities. The reservoir is a shallow vessel holding 160 liters of water the surface of which can without inconvenience be kept within $\pm$ 50^{mm} of a constant point. A rubber hose of 18^{mm} inside diameter conducts the water in a vertical column to the apparatus. A piece of smaller and more flexible tube is used just above the nozzle where the inlet pinch clamp is applied.

9. The hand rest. This is a special support to be used when the outer surface of the index finger is to be experimented upon. It is so constructed that the index finger and the thumb may rest upon a support and the other fingers brace themselves firmly and comfortably so as to obtain perfect stillness of the index finger without interfering with its circulation. A wooden cylinder stands on a base board and carries on its top a hard rubber plate 2^{mm} thick. The thumb and index finger rest upon this plate and the other fingers grasp the pillar below, while the forearm and side of the hand rest upon the base.

Experiments.

The rate of change was varied in successive steps while the other experimental factors were kept constant. Five rates were selected such that the slowest was as slow as could generally be perceived upon the present standard and the fastest as fast as the present apparatus and method would admit. The other rates were taken between these two extremes so that the increase in pressure per second upon a standard of 5^{g} by the respective rates was as follows: 0.18^{g}, 1.10^{g}, 2.85^{g}, 4.83^{g}, and 6.63^{g}. The standard, or initial pressure, of 5^{g} was applied to a circular area 5^{mm} in diameter on the outer side of the middle of the third phalanx of the right hand index finger. The hand support was so adjusted that the finger in position upon it came as near the stimulus point as it could without touching, or about 0.3^{mm}.

The observer and the experimenter sat on opposite sides of the table

with an opaque screen between them. The observer occupied a comfortable position with his finger on the hand support and kept his eyes closed during the trials. By the signal "one" he was warned to be ready; after "two" the initial pressure was applied and about two seconds after this had been done "three" signified the beginning of the increase in pressure. Further instructions to the observers were as follows: "The pressure may increase and it may not; as soon as you are sure that it has increased, say 'up' as promptly as possible. Make sure that you have the same degree of certainty in all trials." This standard of certainty was fixed by a few preliminary trials. If the observer thought that he had not kept the standard of certainty or had suffered any disturbance he was required to call at once for a repetition of the trial. No observer was allowed to see the experimenter's side of the apparatus until all the experiments were completed.

To estimate the distortion due to the order of sequence of the rates, they were taken in rotation in opposite orders by successive observers, and the experiments were begun at different steps in the series in a systematic manner. They were also taken in the double fatigue series, i. e., half the number of trials on each point were made in going through the series the first time and then the rest were made by repeating it in the reverse order. A brief rest was made at the middle of the experiment; the whole lasted about one hour. The results for thirteen observers who tried this experiment are contained in Table I and are represented graphically in Figure 1.

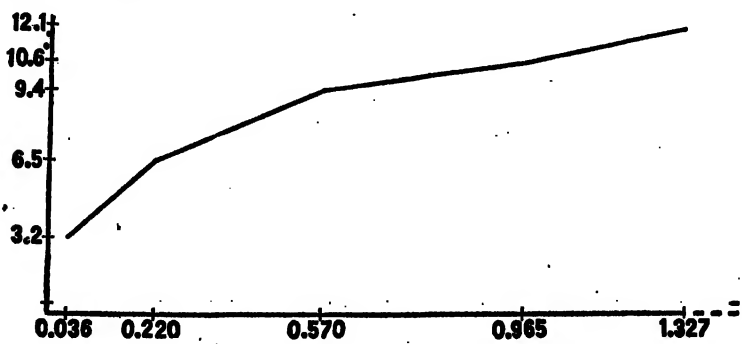


FIG. 1.

The horizontal axis in this figure is marked off into parts according to the γ data in Table I, i. e., proportional to the part of the initial stimulus by which the increase was made per second.

The lowest point marked on the curve to the left is 0.35^s which is the increment when the change is made most slowly. The same over the dotted line to the right indicates how far the curve must drop as the rate increases to the instantaneous. This result is transferred from the third series of experiments.

The law discernable in the table is this: Within the limits of the investigation the amount of the least perceptible increment rises with the increase in the rate, i. e., the faster the increase in pressure the larger is

TABLE I.

Least perceptible increase in a pressure of five grams at different rates.

	I		II		III		IV		V	
α	0.18		1.10		2.85		4.83		6.63	
β	5.55		0.91		0.35		0.21		0.15	
γ	0.04		0.22		0.57		0.97		1.33	
	Δ	d	Δ	d	Δ	d	Δ	d	Δ	d
A. B.	3.4	1.9	4.5	1.9	5.9	2.6	6.9	2.7	7.4	1.1
F. B.	5.2	1.6	4.0	1.9	8.8	2.6	8.4	1.6	7.4	1.1
S. P.	3.1	2.1	9.0	4.8	16.7	3.6	19.5	5.7	11.6	4.9
G. O.	6.3	2.4	10.6	1.5	11.4	4.6	13.4	1.5	16.9	2.6
M. A.	2.8	1.4	5.2	0.7	7.2	1.9	10.4	1.9	12.5	2.8
A. N.	2.9	0.9	4.6	1.3	9.8	2.3	13.9	3.9	15.0	3.7
E. B.	1.9	1.1	6.9	3.1	10.3	6.7	10.2	2.0	14.0	2.6
G. H.	2.6	0.9	4.9	1.6	5.4	0.9	9.8	1.3	11.4	4.4
S. K.	1.8	0.9	5.5	1.4	7.0	1.0	6.0	1.4	6.1	0.9
A. H.	1.8	1.8	6.1	1.8	6.4	2.0	8.9	0.9	9.0	2.8
P. P.	3.1	3.4	7.6	4.0	11.8	4.5	8.4	4.3	12.6	3.8
M. J.	2.7	3.7	8.2	3.0	10.4	2.1	11.4	2.1	15.5	4.2
A. S.	4.0	1.5	7.7	3.7	10.6	2.3	11.1	3.1	17.8	2.9
Average	3.2	1.8	6.5	2.4	9.4	2.8	10.6	2.4	12.1	2.9
Time	17.7^s		5.9^s		3.3^s		2.2^s		1.8^s	

The unit of measurement is the gram.

The number of measurements in each case is $n = 10$, of which the median[1] is taken.

Initials, the observers.

Roman numerals, the different rates.

Δ, the increment in grams.

d, mean variation; to find the mean variation for the series divide each of these by $\sqrt{n} = 3.2$.

α, number of grams of increase per second.

β, time to increase one gram, in seconds.

γ, part of the initial stimulus to which the increase amounts per second.

Time, the time represented by the average increment for all observers at each rate.

the size of the increment which is just perceptible. These limits include those which we experience most in normal life. But, referring to the curve, near the two ends there must be deflections of the curve in

[1] In the present research I have used the median in all the experiments with the reaction method; the average has been used with other methods. This is because, by the nature of the experiments, the variation is larger and there are more abnormal records by the former method. For the account of the median and its relation to the average see SCRIPTURE, *On mean values for direct measurements*, Stud. Yale Psych. Lab., 1894 II 1.

opposite directions if it is to be extended, i. e., if extended on the left the curve must soon reach an almost vertical direction and the extension of the other end must bend in some way so as to eventually reach the point which represents the increment in instantaneous change. The law of such deflections must be determined by future investigation.

The experiment was repeated three times upon one observer, M. J., at intervals of two weeks, each time under similar circumstances. The judgments in the successive experiments were equally unbiased, except in so far as they were influenced by the pressure sensations. The final averages for the three experiments are as follows: Rate I, Δ 2.8^g, d 0.1^g; Rate II, Δ 9.1^g, d 1.6^g; Rate III, Δ 11.3^g, d 1.6^g; Rate IV, Δ 13.1^g, d 1.2^g; Rate V, Δ 13.7^g, d 1.5^g. The results indicate that the rate influence is definite and persistent for these trials. This remarkable consistency, as well as the agreement of the thirteen observers above, can only be accounted for by assuming a definite time influence which corresponds to this variation. The general law here found has an extensive application to the whole sensory side of our mental experience and involves some disputed points. I will, therefore, give a brief critical estimate of the apparatus, the method and the conditions adopted. Much of what is here said applies, also, to the following series of experiments.

Critical estimate.

1. The apparatus. The only noticeable jarring of the apparatus came from the jarring of the building, and this disturbance was somewhat reduced by placing the experimenting table on sand bags. Furthermore the above experiments were made in the evening when it was comparatively quiet in the building. The variableness in the level of the source and the mouth of the stream caused some degree of inaccuracy. The two levels were placed so far apart vertically that the necessary variation in the level of the mouth would not materially affect the results beyond the degree of accuracy here required. The time for the water to rise through the first 100^{mm} of the graduation tube was to the time to rise through the second 100^{mm} above the zero of the same as 38 is to 39. This error is negligible because it affects all rates similarly and practically equal for proportional increments by the various rates. Since most of the measurements came within the limit of the first 200^{mm} the rates adopted were determined empirically for the average of this distance. This determination was made to a more than sufficient degree of accuracy by the graphic method of recording time.

The adjustment of the zero point of the column of water could be

made with an accuracy of $\pm \frac{1}{2}^{mm}$ which equals about $\frac{1}{28}$ of a gram by displacement. There is again a possible error of $\pm \frac{1}{2}^{mm}$, by the same unit, in the adjustment of the hand rest. Both these errors affect the standard pressure and can only affect the increment in an indirect way.

2. Method. The main reasons for using the reaction method here are: (*a*) It is time-saving, which is a vital point when a long series of records must be taken. (*b*) It does not carry with it any suggestions as to what may be desired or expected. (*c*) It is easier to interpret the results by this method than by any other. The results attained by this method need to be corroborated by other methods and that will be done, but I must here point out some of the sources of error of the method in its present application. The observer reacted with a vocal sound and I, as experimenter, made a sight reaction to that sound. This latter reaction is negligible because my eye followed the reading point as a point of regard. The sensory time in the observer's reaction should be counted to the record, i. e., the record should include the time from the beginning of the physical change to the moment it was perceived as a change, but not the motor element in the reaction. This I tried to eliminate directly in each trial by means of a subjective estimate. After some practice in sight readings of this kind I acquired some skill in estimating equivalents on the scale to the amounts lost by the observer's reaction at the various rates. I could hear the very beginning of the vocalization of the *u* in "up." But the allowance to be made had to vary with the definiteness with which this sound was uttered. I was aware of the common illusion of motion as well as of the difficulty of perceiving two simultaneous impressions in different senses. I found difficulty only in the fastest rate, but even here the possible error would be small in comparison with the whole records and the corresponding mean variations. This method of eliminating the reaction-time is not fully satisfactory, but it is superior to the previous methods that have been proposed for similar purposes.

Do we want the naïve judgment of the unpracticed but skilled observer? or the discriminative and critical judgment of the experienced observer who is familiar with the conditions and elementary processes upon which his judgment is based and gives his decision after having taken all known factors into consideration? While the latter is necessary in order to make a detailed analysis of the facts, the former is necessary for the establishment of the facts. Though it involves more than double the labor of the other method, I have made it a characteristic of this research that the facts shall be obtained as they appear without analysis in the common experience of the scientific mind. No one of my observers knew what to expect and they were expressly cautioned not

to make any guesses with consequent conscious or unconscious corrections.

The observer was directed to react when he could distinguish "change" from "no change." In this series I did not have any regular system of control experiments, i. e., trials in which no stimulus was applied. They were interspersed irregularly and by them I satisfied myself in regard to the necessary absence of illusion. The danger of illusion was emphasized in the preliminary trials. If the illusion took place then, the trial immediately following would show the trace of a reacting influence in overcautiousness and consequent missing of the standard. In such cases the preliminary practice was continued until the observer had settled upon a normal standard.

3. Conditions of the experiment. The standard pressure may seem light, but it is adapted to the place experimented upon. It was advisable to use a light stimulus which would not produce a deadening effect upon the nerves under long continued pressure. A light pressure on a small area produces a simpler and less disturbing sensation than a heavy pressure, which is liable to produce sensations of strain in parts not directly stimulated. It is also important to avoid pain.

The point upon the first finger was chosen for stimulation because it admits of being kept in a horizontal plane when the rest of the body is in a comfortable position. The place is of a good sensitiveness and free from hairs.

The slowest rate here used was determined by preliminary experiments in which smaller floats were used. It was then found that the change would not be perceived at all, in the slowest rates, even when it amounted to four or six times the original stimulus. The pressure sensation would either be entirely lost or else it would continue indefinitely to seem as but a fraction of the standard. 6.18^g per second was found to be about the slowest rate per second by which the pressure might rise and still be perceptible every time under normal conditions. The fastest rate was taken within safe limits, and rates above that were reserved for a separate test.

II. Variation in sensitiveness to change as depending on the delay of the stimulus.

In previous experiments with sight and sound[1] I found that when a stimulus near the threshold is delayed beyond a certain time at which it

[1] Seashore, *Measurements of illusions and hallucinations in normal life*, Stud. Yale Psych. Lab., 1895 III 36, 50.

may be expected, its threshold is lowered, and, within certain limits, this is proportional to the delay. If this law applies to pressure, a part of the facts established in the first series of experiments will be explained by it. The application of the law of delay to this particular case was tested in the following manner:

Apparatus *A* was used just as in the foregoing series but with only one rate, namely 1.10^g increase per second, which is 0.22 per second of the standard. Counting from the end of 2^s allowed for the perception of the original pressure, the increase was not begun until after a delay for the respective sets of trials as follows: I, 0^s; II, 5^s; III, 10^s; IV, 15^s; V, 20^s; and VI, 25^s. In other respects the general methods and conditions were the same as in the first series. There was no suggestion by which the observer was led to expect the change to be felt at any definite time. He was not aware of the delay; he only knew that he would feel a gradual change and that he should begin to look for it at the given signal. Nothing was stated as to when it would begin physically. He learned, however, from the preliminary trials that it would take different time-intervals for the change to become perceptible. Hence this is different from the cases of suggestion in which the observer is led to expect the stimulus at a definite moment. Here the conditions of expectation and general preparation were similar to those in the foregoing series. It is a case of suggestion that works through the variation of time-influence in ordinary perception.

TABLE II.

Variation in sensitiveness as resulting from delay of the stimulus.

	0^s		5^s		10^s		15^s		20^s		25^s	
	Δ	d	Δ	d	Δ	d	Δ	d	Δ	d	Δ	d
A. H.	7.6	3.1	6.7	2.2	4.0	2.0	3.8	2.2	3.6	2.0	4.1	1.4
P. D.	8.3	3.4	6.0	1.6	4.7	0.9	4.0	1.6	2.6	1.2	3.4	1.4
P. P.	13.2	4.5	5.1	1.2	5.1	2.5	5.8	1.9	3.2	1.2	3.5	0.9
A. B.	5.4	1.4	3.5	1.3	2.9	0.6	2.1	0.7	2.2	0.6	1.9	0.4
D. S.	6.6	3.8	4.1	2.8	5.1	1.5	5.1	2.1	3.1	2.2	4.1	1.3
J. M.	5.8	2.1	4.3	1.1	2.9	1.2	2.7	0.4	2.7	0.9	2.9	0.5
A. S.	20.0	3.0	17.1	2.9	12.9	3.0	11.9	4.1	13.4	4.3	13.1	3.7
Ave.	9.6	3.0	6.7	1.9	5.4	1.7	5.1	1.9	4.6	1.8	4.7	1.4

The unit of measurement is the gram.

The number of measurements in each case is $n=10$, of which the median is taken.

The delay of the stimulus is indicated in seconds at the head of each column.

Δ, the threshold increment.

d, mean variation; the mean variation for the series is found by dividing by $\sqrt{n} = 3.2$.

The trials were made in the double fatigue order. Surprise and the disturbance of abrupt transitions were avoided. The control trials were used freely in the preliminary trials but not during the experiment. Table II contains a summary of ten trials on each point by each of seven observers. The figures give the medians, and the average of these is taken for the final summary. There is a remarkable uniformity in the results. The abnormal record of the last observer is accounted for by the fact that his hand was callous.

The table shows that the threshold decreases, i. e., the sensitiveness increases, as the delay is extended. This law is most noticeable in the first five or ten seconds and seems to extend only to about twenty seconds.

The results may best be interpreted by means of the comparison in Figure 2. The short curve represents the results of the first series of ex-

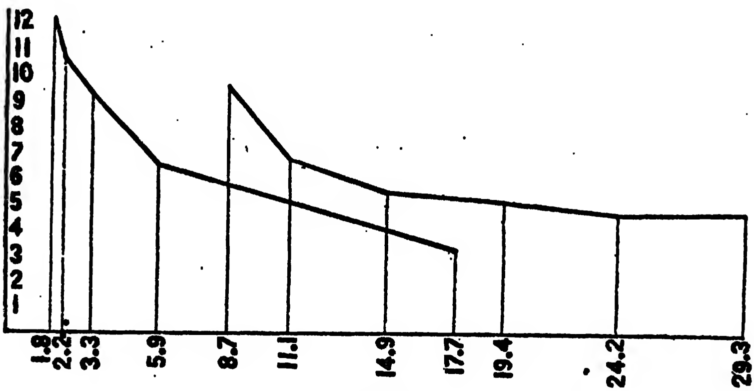


FIG. 2.

periments, showing the relation of the threshold to the time which it took to produce it. The number of seconds is laid off as the abscissa and the number of grams as the ordinate. The longer curve shows the same for the present series. Within the limits of time occupied in the first series (17.7 sec.) the threshold of difference is lowered as the time increases. Beyond that limit the delay does not seem to have any power to lessen the increment. The rate, which is actually the same in both cases, requires the largest increment in the series in which it occupies an extreme point.

A great part of this variation may be explained by the fact that the longer the time the greater the expectancy will be and the summation of suggestive elements will be on a constant increase. The smaller signs

of change come directly into the focus of attention, a greater number of them will be noticed and those noticed will be magnified. This implies that the variation of the threshold with the rate is not entirely because of the difference in impression that quick or slow rates of change make, but largely because of the different attitude of mental preparedness which is caused by different time relations. Though the observers tried to be equally attentive all the time there was a semi-conscious reinforcement of attention as time went on. When the signs of change came soon they had to compete with more rival sensational elements than if they came later. According to the conditions of the experiment there could scarcely be any surprise, but we may characterize the different states of mind by saying that in the fast rates the observer was open to conviction, while in the slower changes he more anxiously sought some imaged facts of assurance.

The fast rates are probably affected by contiguity with the slow, and likewise the reverse. The faster rates were, perhaps, at a disadvantage. It is probable that if the highest point in each curve had been established separately, without reference to any other rate, it would have been lower in both cases. Yet those would be entirely different conditions. If one rate, or time of change, is taken separately, the time for the change to be felt will be known; it will be envisaged more definitely; the attention will be sharply focused at the expected moment of change and no attention-energy will be scattered as above. Both conditions are facts of ordinary experience and it would be interesting to compare them. One form of the latter condition will be taken up in the next series of experiments.

Fatigue makes a light weight or pressure feel lighter. This is true for 5^g. How does that affect those curves or their continuation? Does it have the effect of lessening the standard and thus making the increments proportionally greater during the time extension? Or, does it work in the opposite way so that the amount of the standard, plus the increment, is constantly lessened, necessitating a longer time to make the pressure feel heavier than at first? Both are true, i. e., there is a certain limit at which the amount lost by fatigue is just equal to the increase at a certain rate. This point lies beyond the lower end of the short curve. Then the weight would feel the same *ad infinitum* if there were no fluctuations in this limit. If the change is slower, however, several possibilities of sensation-changes are open, but it is not probable that any increase in pressure will be felt before pain sets in and the experiment for pressure must be discontinued. But if the rate of increase is faster than the rate of falling off by fatigue, the standard will actually

seem smaller as time is extended, as in the present series, and the increment, which is largely detected by feelings of change, will be felt larger in proportion.

III. Threshold for instantaneous increase in pressure.

Apparatus B.

The compound pressure balance here described was constructed primarily to serve as a means by which a standard pressure over a definite area might be applied and then increased at any moment without jarring the stimulus point or causing any disturbance except absolute increase in pressure. It consists of two coördinated balances, one of which is apparatus *A* with the only exception that a tapering rubber point (*T*) is substituted for the original pressure point. The other balance consists of a light steel beam 300^{mm} long on one side of a knife-edge bearing with the balancing mass on the other side. The pressure point is a cylinder inserted at the end of the beam which is supported from a frame by a pair of electro-magnets. This part of the frame is capable of minute adjustment in height. The frame carries a millimeter scale parallel to the beam. A sliding weight on the beam carries a pointer which indicates the position of the weight on the scale; the change of weight at the pressure point (*P*) is proportional to the distance over which the weight is from the fulcrum. A light arm projects from the rear end of the cylindrical counterbalance for the purpose of affording leverage for the action of pressure from the other balance.

When the two balances are brought together, the point *T* in balance *A* is brought to bear on the leverage arm in the other balance, and can be removed by the guide lever (apparatus *A* 6) without friction or jarring. By this combination of the two balances we secure a pressure point which keeps a rigid position, a means of retaining the standard pressure constant, and an instantaneous change or a gradual change in pressure at any desired rate.

To illustrate the case of instantaneous change, suppose that the balance is set with an initial pressure of 5^{g} at *P*. This is supported by the electro-magnets at a definite distance (½^{mm}) from the surface to be pressed upon. Then if we want to prepare to increase that by, e. g., 1^{g} after it has been applied, the weight on the beam is moved from the fulcrum until the scale indicates that the movement is equal to 1^{g} at *P*. Then balance *A* is adjusted to press with a force of 1^{g} by *T*. This 1^{g} counterbalances the 1^{g} just added to *P* and we have again the standard weight at

P. Opening the magnet circuit always places the standard pressure with the same momentum. To obtain the 1^g increase upon the standard the point *T* is lifted vertically by a rapid movement of the guide lever (*A* 6). The 1^g is of course transferred directly to the point *P* without any movement of the beam except through the extra indentation which the 1^g causes on the skin.

I have only had time to make one of the tests for which this apparatus is intended. This test consisted in finding the least perceptible increase when the change was made instantaneously. The standard pressure and the area were the same as before; the general method was also the same. At a signal the observer got ready and about two seconds later the point *P* was applied by releasing the magnets. The increase was made about two seconds after this. The threshold was approached in both directions by steps with a constant difference of 0.2^g. The observer simply stated whether he perceived the change or not. Control trials were interspersed irregularly. The average of the complete measurements on each of seven observers is given in Table III. The figures denote the smallest increment above which all were perceived.

TABLE III.

Threshold of instantaneous increase in a pressure of 5^g.

	Δ	d
A. N.	0.26	0.08
M. A.	0.34	0.07
J. M.	0.34	0.08
G. O.	0.17	0.06
A. S.	0.64	0.15
P. D.	0.34	0.07
P. P.	0.36	0.07
	0.35	0.09

The unit of measurement is the gram.

The number of measurements in each case is $n=10$, of which the median is taken.

Δ, threshold increment.

d, mean variation; the mean variation for the series can be found by dividing this by $\sqrt{n}=3.2$.

The main value of these results lies in that they establish one end of the curve in Figure 1 as it would terminate if continued. The curve has to fall from its highest point 12.1^g to this point 0.35^g. This suggests an important problem, namely, in terms of the figure, what is the shape of the curve which must connect these two points? This will be answered for somewhat different conditions in a following series of ex-

periments. The present threshold meanwhile gives a standard in comparison with which we must interpret all the previous measurements on gradual change. Thus, the slowest gradual increase requires a threshold nine times as high; and the fastest a threshold thirty-five times as high as the threshold for instantaneous difference. In making this comparison "instantaneous" must be taken in a relative sense (as it always must) according to the above details, and it must be remembered that these two thresholds were found by different methods.

Psychologically the two judgments of gradual and instantaneous differentiation are not only made under totally different conditions of attention and expectation, but there is also an entirely different grouping of the sensations which form the basis for the discrimination.

IV. Effect of the rate of change upon the perception of increase in weight.

Apparatus C; Experiments.

An apparatus is needed by means of which gradual changes in the weight of a lifted object can be made and measured. Apparatus *C*, which was constructed for this purpose, consists of the following parts, used in conjunction with apparatus *A*:

1. The weight cell. This is a polished hard-rubber cylinder with a diameter of 21^{mm} and a height of 75^{mm}. Its own weight, 25^{g}, may be increased to different amounts by placing weights inside. A silk cord hangs from the bottom, by which weights may be attached.

2. The arm support. A board base is fixed in such a position that the arm from the elbow may rest upon it in a horizontal position. The weight cell stands on this in a position to be grasped comfortably. The cord from the cell runs vertically through a hole in the board to the stimulus end of balance *A*.

Apparatus *C* works on the same principle as apparatus *A*, the only difference being that the weight is exerted on a lifted cell instead of a pressing point. To illustrate by an example, let it be desired to obtain a measured gradual increase on a standard of 40^{g} weight in a cell. The cell itself weighs 25^{g} and we add 15^{g} by weight placed inside of the stimulus rod, to whose top the cell is attached. Since this rod is counterbalanced by the float, the 15^{g} are added to the weight of the cell when the observer lifts the cell, say 2^{mm} from the base. At that point the standard will be reached. The water in the graduated tube is then allowed to rise at some definite rate and as the float is immersed weight is transferred to the cell.

The same general method that was used in the study of pressure was here applied in the study of the so-called muscle sense, the word being used in its widest significance as including all the sensations by means of which we estimate lifted weight. The aim was to determine whether there is any law for muscle sense that corresponds to the law of rate influence that we have found for pressure, and, if so, to observe some of the relations between the two.

TABLE IV.

Least perceptible increase in a lifted weight of forty grams at different rates.

	I		II		III		
α	0.18		1.10		6.63		
β	5.55		0.91		0.15		
γ	0.005		0.028		0.166		
	Δ	d	Δ	d	Δ	d	ε
J. L.	3.3	1.1	11.5	4.0	20.3	2.1	0
V. S.	1.7	0.4	6.1	1.8	9.7	5.0	0
M. M.	5.3	1.4	11.0	2.4	18.0	4.4	0
J. P.	12.0	5.4	14.9	4.0	21.9	4.9	0
W. J.	2.4	1.0	6.6	1.5	14.8	4.9	43
A. S.	4.0	1.3	12.1	3.6	17.5	2.4	43
F. K.	3.9	0.5	12.4	2.6	17.1	5.3	0
E. J.	6.0	2.3	13.8	4.9	13.5	4.9	0
C. C.	4.0	2.4	7.3	3.4	13.7	4.2	0
Average,	4.7	1.8	10.6	3.1	16.3	4.2	
Time,	26.1^s		9.6^s		2.5^s		

The unit of measurement is the gram.

The number of measurements in each case is $n=10$, of which the median is taken.

I, II, III, rates of increase.

α, number of grams of increase per second.

β, time to increase 1^g.

γ, increase per second as a fraction of the initial stimulus.

Δ, threshold increment.

d, mean variation; to find the mean variation for the series divide by $\sqrt{n}=3.2$.

ε, percentage of the control trials in which illusions occurred.

The standard was taken as 40^g, because that weight in the given cell is favorable for a distinct feeling of weight and does not cause noticeable fatigue ~~very soon~~. Only three rates were employed and these were the same as I, II and V in the first series; they gave an increase of 0.18^g, 1.10^g and 6.63^g per second, respectively.

The observer shut his eyes and grasped the cell at the middle between the thumb and the first two fingers in such a way that when he had raised

the cell 2^{mm} from the base the side of the hand and the little finger rested on the base by their full length and the cell was held upright. The position was comfortable and could easily be retained for the required time. The observer grasped the cell as lightly as possible. As soon as the correct position had been secured the signal was given which meant that except in the control trials the physical change would begin in two seconds. The reaction was made by saying "up" and the results were read as before. Nine persons made the complete experiment, which consisted of ten trials on each rate, exclusive of the control trials. The summary is contained in Table IV.

From one to five control trials were interspersed with each ten regular trials. The column giving the percentage of these trials which resulted in illusions gives an index to the reliability of the discrimination. All but two are perfectly reliable in that they have chosen the standard threshold so high that there is no danger of confusion. The high percentage of errors for the two must, however, not be interpreted to mean that such a percentage of the total number of trials may be considered as illusions, for in each case there were thirty trials in which the regular change was made and only seven in which the stimulus was withheld. All three illusions out of the five possible were in rate I for W.J., and for A.S. two out of four possible were in rate I and one out of two possible in rate II. The value of these percentages depends upon the relation between the number of control trials to the number of regular trials as well as upon the degree to which a trial with no sensation of change was expected. The effect of the rate influence is as marked for these observers as for the others and their mean variation is not excessive. This argues that, since they had nothing but the direct sensation to judge by, the real signs of change must have been present in a much larger proportion of trials than the above percentages would indicate. The error cannot be explained as due to the ordinary premature automatic reaction, for then the mean variation should have been much larger.

The figures in the table express the law that, for the three rates investigated, the threshold of perceptible increase in lifted weights is higher in fast rates than in slow rates. This accords with the law we found for pressure. The relation of the two will be discussed later.

V. Threshold for instantaneous increase in weight.

Apparatus D; Experiments.

This problem requires an apparatus by which the standard weight of a body may be increased instantaneously without causing any other dis-

turbance. This was accomplished by a compound weight balance. The cell (C_1) and the arm rest (C_2) are used as in the foregoing series. A weight-pan is suspended by a silk cord, branching out from the center of the bottom of the cell, 400^{mm} below it. Midway between the cell and the weight-pan there is a light fibre balance beam 140^{mm} long with its fulcrum at the middle. It is adjusted with one extremity perpendicular over the pan and attached to it by a cord which passes between the branching cords and is so fastened to the pan that changing the support of the pan from this cord to the branching cords, or the reverse, will not cause the pan to shake. At the other end a hook is suspended by a cord 200^{mm} long. Upon this a series of gram weights was fitted to be hooked firmly. The hook is light ($\frac{1}{2}^{g}$) and makes the weights conveniently interchangeable. At first the instantaneous increase was made by means of a weight acting over a pulley by a cord from the hook end of the balance beam. This weight was allowed to drop 100^{mm} with the cord slackened 90^{mm}; thus the hook end of the balance would be elevated 10^{mm} at a definable rate. But the present method required that the change should be made noiselessly; therefore at the risk of some irregularity, I simply raised the weight by pulling a cord perpendicularly from the hook as quickly as possible.

The plan of the apparatus may be explained better by an example. Suppose we want to get an increase of 1^{g} on 40^{g} lifted by the cell. The cell weighs 25^{g} and enough weight is added to the pan to make it weigh 15^{g}. Since the 15^{g} are supported by the cell its total weight is 40^{g}. We then place the 1^{g} increment in the pan and counterbalance it by 1^{g} on the hook (including the weight of the hook); the two weights on the balance, therefore, do not act upon the weight of the cell. The observer grasps the cell and lifts it 2^{mm}; this makes the balance beam stand in a horizontal position. The grasp is made in such a manner that the whole side of the hand rests upon the support in a position that can easily be retained during a prolonged experiment. He is then lifting the standard weight, but when the hook-weight is raised suddenly its counterbalance is transferred to the support of the pan without any movement of the balance beam. I was able to elevate the hook-weight as quickly as it would start to fall by its own gravity, or faster; therefore, the increment was transferred to the new support at the rate that it would assume by its own weight when beginning to fall, i. e., the increase was made by simply releasing the support of the required amount without imparting motion to the standard weight. By this method any instantaneous increase may be made without impact. It is evident that by reversing the action of he balance a decrease in weight may be made equally well.

This series of experiments was made on the same observers as the fourth series, and under similar circumstances, in order that the two sets of results might be comparable. They were made during the same period, this experiment being made alternately before and after the other. The point to be determined here was the threshold for the perception of a so-called instantaneous increase in the weight of a body lifted by the rested hand. A form of the method of minimum variation was employed. The steps varied by one gram each and were taken alternately ascending and descending the series. In ascending, the steps of change were continued until the observer had perceived the increment correctly three times in succession; and, in descending, the series of steps was begun with the highest one of the ascending series or by one above it if this series was low. At a signal the observer lifted the cell to the 2^{mm} limit and as soon as steadiness was attained in this position another signal warned him to watch for an increase, to which he should react by saying "up" at the moment he perceived it. The change was made from two to six seconds after this signal. The observer's ability to react just at the right time was considered a criterion for his certainty and accuracy. The time of making the change was varied irregularly within this region of four seconds. If he reacted perceptibly before or after the change, due allowance for the reaction-time being made, the fact was recorded as an error or illusion. Of course, failure to react indicated that the stimulus was below the threshold. This time-criterion was chosen in preference to the method of control trials in order to make the experiment short. Instead of concentrating the attention on the moment two seconds after the signal, it here had to be scattered over a time of four seconds. This, presumably, tended to raise the threshold. Upon a definite inquiry each observer testified that he had not perceived any suggestion as to the moment of change except by direct feeling of change in weight.

The results are contained in Table V; the initials of the observers will aid in the comparison of the individual records here with those in Table IV.

The Δ value marks an arbitrary limit. With careful observers it may be considered a pretty safe limit, denoting the point above which we may expect to find all increments perceptible under similar conditions. The Δ value must be interpreted with reference to the mean variations and the figures in the first sections of the table. According to the table 4.7^{g} would be perceptible about seven times out of ten, or 70 per cent. of the trials. This percentage is brought down so low because it is an average for different observers and not for successive trials on the same observer. The last column gives the number of times each observer reacted wrongly.

In comparing this and the preceding table we notice the striking coincidence that the threshold for instantaneous change is the same as the threshold for the slowest gradual change. Between those two points the curve changes to nearly four times that height (see Figure 3). Here the relation between the instantaneous and the very slow increments is very different from the corresponding relations for pressure, where the instantaneous increment is only about one-ninth of the slowest.

TABLE V.

Threshold of instantaneous increase in a lifted weight of 40g.

	1g	2g	3g	4g	5g	6g	7g	Δ	d	e
J. L.	1	4	6	4	8	10		4.6	1.1	1
V. S.	0	0	6	8	10			3.6	0.7	0
M. M.	0	0	1	7	10			4.2	0.4	0
J. P.	0	0	0	2	4	10		5.6	0.5	0
W. J.	1	7	5	9	10			3.4	0.8	3
A. S.	0	0	0	2	6	5	10	6.2	0.8	2
F. K.	0	0	1	2	9	10		4.9	0.4	0
E. J.	0	0	0	3	8	10		5.0	0.4	0
C. C.	1	2	1	4	8	10		4.9	0.5	5
	0.3	1.4	2.2	4.6	8.1	9.4	10.0	4.7	0.6	

The unit of measurement is the gram.

The number of complete determinations of the threshold for each observer is $n = 10$.

The increments are denoted by the numbers at the heads of the columns.

The numbers below these show how many times, out of ten possible, each was perceived.

Δ, the average increment above which the next two are correctly perceived, hence the threshold.

d, mean variation; the mean variation for the series is found by dividing each of these by $\sqrt{n} = 3.2$.

e, total number of errors.

Experiments were made upon six observers to study the effect of delay of the stimulus. Instead of devoting a special section to them I will make a brief statement here.

Using the identical apparatus described above, I found how the threshold varied if the stimulus was withheld after the signal for the number of seconds that the averages in series IV indicate, namely, 2.5s, 9.6s and 26.1s, i. e., the time it required to perceive the change at the three rates of gradual increase. Ten trials were made on each of the four increments: 3g, 4g, 5g and 6g. The results may be stated in a general way in terms of the percentage of those increments which were perceived. These are: for 2.5s, 63%; for 9.6s, 69%; and for 26.1s, 67%. The difference is not large enough to indicate any tendency toward a systematic variation.

The elements of fatigue and distribution of attention spoken of in the

second series seem to counterbalance each other here. Thus after the 26.1^s delay the standard seems lighter on account of the fatigue; but an instantaneous increase at that point will not be affected by fatigue, and will, therefore, appear larger in proportion to the standard at that point than at any previous point. On the other hand, at the end of 2.5^s there is no noticeable effect of fatigue, but the attention is not yet so strongly focused.

The present experiments should be compared with those in series II. Here the change was instantaneous, there gradual. The difference in the results points to the fact that the methods of perceiving change are entirely different in the two cases.

VI. Verification of series I and IV.

To increase the data found in series IV and to verify the law expressed in the results of series I and IV by means of a different method, the latter series of experiments was repeated by a form of the method of minimum variation. The only alteration necessary in apparatus *C* was to insert a scale reading in grams instead of the millimeter scale on the graduated tube. The steps of increase in the experiment differed by two grams each, running from 2^g to 20^g.

I tried different steps at random and considered a determination complete when I had found at least three consecutive steps in which the increment had been correctly perceived and all the steps below this had been tried. I was fully aware of the influence this procedure has upon the mean variation, but it secured a good distribution of attention and served as a sort of control method in that the observer had no means of knowing whether the increment should be a large or a small one as he would if the threshold had been approached by steps taken in regular order. If in the large steps the observer was sure that he felt an increase before the full amount had been reached, he was allowed to signify this in order to save time, but such a reaction was recorded as if only the whole increment had been perceived. No steps higher than 20^g were tried. Five complete determinations were made for each rate by each observer.

At the signal the observer lifted the 40^g cell to the standard position, and at another signal he began to watch for an increase in weight which began two seconds later except in the control trials. A final signal was given at the end of the increment and upon this the observer had to reply immediately by one of three answers, namely: "change," "no change," or "uncertain."

The method of manipulating the apparatus may be understood from the explanation in series IV; the main difference was that here definite amounts of increase were produced and the observer stated whether he perceived them or not, while there the change continued until he reacted.

The possible inaccuracy in reaching the exact increment in the fastest rate was $\pm 0.2^g$. If a larger error than that was made the trial was repeated. The variation by unsteadiness of the observer's hand may introduce a possible error of $\pm 0.2^g$. These are the only two marked sources of error. The first affects only the fastest rate.

The results for the observers are contained in Table VI. The first part of the table shows the numbers of R (change perceived) and U (uncertain) answers that were given out of five trials on each increment. At the right hand end of each line I have omitted all but the first "5" when this is the first of three successive fives. The R and the U trials are recorded separately and the reader may distribute the U trials as he thinks best. A general expression of the results may be gotten by a study of the R trials alone.

Table VI.

Threshold of increase in a lifted weight of 40^g.

			2^g	4^g	6^g	8^g	10^g	12^g	14^g	16^g	18^g	20^g	Δ	a
M. M.	I	R	3	5									2.8	1.0
		U	2											
	II	R		1	3	4	4	5					7.2	1.0
		U		2	2									
	III	R			1	3	3	5					10.4	1.2
		U	1	3	2		1							
F. C.	I	R	3	5	3	5							5.4	2.2
		U												
	II	R		1	5								5.6	0.6
		U		2										
	III	R		1	2	3	5						8.4	1.2
		U		1		2								
N. H.	I	R	4	4	4	5							4.0	2.4
		U												
	II	R		2	5	5	4						5.2	1.0
		U												
	III	R			2	3	5						8.0	0.8
		U				1								
B. L.	I	R	1	3	5								4.4	1.2
		U	1											
	II	R	1	2		4	4	4					9.2	1.9
		U			3	1								
	II	R			1	3	4	1	5				12.4	2.6
		U						2						

J. P.	I	R		1	3	3	5						7.6	1.9
		U												
	II	R				3	3	4	5				10.0	2.4
		U												
	III	R					2	2	1	1	3	4	16.8	3.0
		U					1		1					
W. J.	I	R	2	3	2	5							6.4	1.9
		U			1									
	II	R			2	4	4	4	5				8.4	2.4
		U			1									
	III	R				2	3	4	4	4	4	4	12.0	3.2
		U			1	1	1		1					
J. R.	I	R	2	2	4	4	4	5					6.4	2.2
		U	2			1								
	II	R		3	4	3	4	5					8.4	2.4
		U				1								
	III	R	1	1	1	2	3	3	4	4	5		12.0	3.2
		U			2									
W. H.	I	R	2	4	5								4.0	0.8
		U		2										
	II	R		4	4	5							5.4	1.5
		U		1	1									
	III	R	1		4	4	4	5					7.6	1.9
		U		2	1									
B. H.	I	R	3	4	5								3.6	1.3
		U												
	II	R	1	3	5	2	2	5					10.0	2.4
		U					1							
	III	R			1	4	3	1	5				13.2	1.3
		U												
R. S.	I	R	5	3	4	5							3.6	1.9
		U		1	1									
	II	R		4	1	5	4	5					8.4	1.4
		U			1									
	III	R			1	2	4	4	5				11.2	1.4
		U		1	3									
Av. % of R	I		50	68	80	94	98	100					4.8	1.7
	II		4	40	58	80	78	94	100				7.6	1.7
	III		4	4	26	52	72	70	78	88	94	96	11.2	2.0

The unit of measurement is the gram.

Number of trials on each point, $n = 10$.

Roman numerals give the rates:

I, 0.18^g per sec.

II, 1.10^g " "

III, 6.63^g " "

R, number of times the reply "change" was given in five trials.

U, number of times the reply "uncertain" was given in five trials.

The difference between 5 and R + U will give the number of replies "no change."

The numbers at the head of the columns denote the increments.

Δ, the threshold above which it is probable that all increments would be perceived.

d, mean variation of Δ; to find the mean variation for the series divide by $\sqrt{n} = 2.2$.

I have here assumed a standard condition which gives a threshold of the same degree of probability in all rates. This is obtained by the conditions upon which the figures of the Δ column in the second part of the table are based, i. e., the first of these consecutive increments that has been correctly perceived is taken for the threshold. With this as a standard, we may compare the rates with each other and, with certain precautions, the general results with those obtained by the reaction method.

There is a remarkable uniformity in the results, considering the delicacy

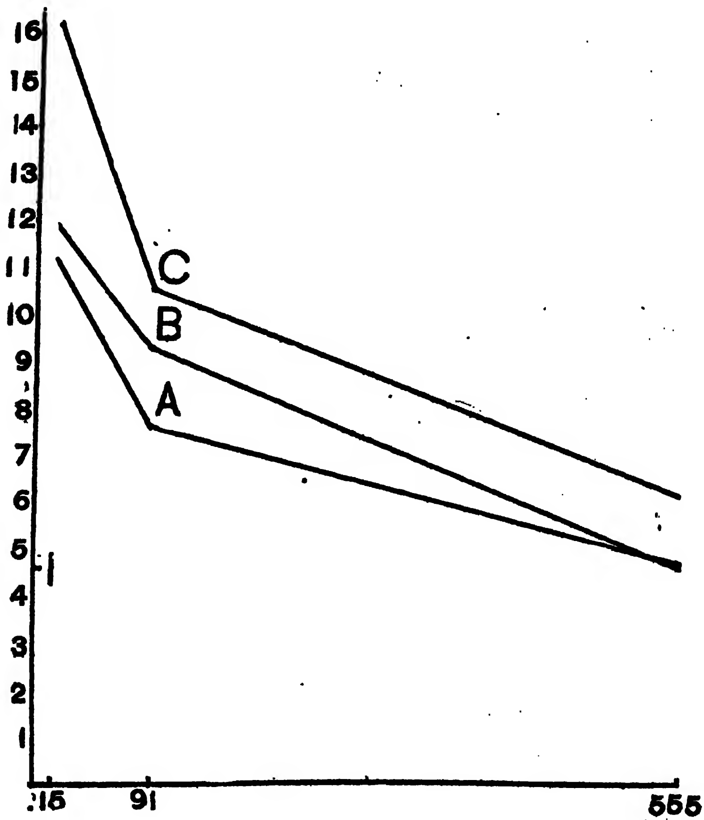


FIG. 3.

A, Results in Table IV.
B, Results in Table VII.
C, Results in Table VI.
The horizontal axis is divided into parts proportioned to the number of grams of increase per second, or, which is the same, to the part per second of the initial stimulus by which the change was made. The increments are laid off in grams as ordinates.

and difficulty of this discrimination and the lack of practice. Bearing in mind the differences in the conditions of these experiments and those

TABLE VII.

Five experiments on the author under conditions similar to those in the preceding table.

			4^s	6^s	8^s	10^s	12^s	14^s	16^s	18^s	Δ	d
A	I	R	1	2	4	5					5.6	0.8
		U	1	2	1							
	II	R				3	4	5			10.8	1.7
		U	1		4	1	1					
	III	R				1	3	5	1	5	15.6	1.8
		U			1	1	1	0	2			
B	I	R	1	3	5	4	4	5			8.0	2.4
		U	1			1						
	II	R			1	2	3	5			11.6	1.4
		U		1	3	2						
	III	R					2	3	5		14.4	1.7
		U		1	3	3	3	2				
C	I	R		4	5						6.4	0.6
		U	4	1								
	II	R			3	5					8.8	1.0
		U	1	2	1							
	III	R			2	2	5				11.6	2.0
		U			2	2						
D	I	R	1	4	4	5					6.0	0.4
		U	2	1								
	II	R			3	5					8.8	1.0
		U		2	1							
	III	R		1	3	4	5				9.2	1.8
		U										
E	I	R	3	4	4	5					5.6	1.9
		U	1	1	1							
	II	R		5							6.0	0.0
		U	1									
	III	R			3	5					8.8	1.0
		U		1								
Ave. % of R	I		24	68	88	96	96	100			6.3	0.7
	II			12	80	88	100				9.2	1.6
	III			4	32	72	80	92	84	100	11.9	2.5

Capitals denote the successive experiments. | Other notation same as in Table VI.

in series IV we may obtain some general conclusions from this comparison:

1. The law of the relation of the increment to the rate of increase established by the previous method in series I and IV is supported and

proved beyond the possibility of a doubt. This applies to series I only indirectly, but the general agreement between the facts and conditions of series I and series IV justifies the deduction in regard to the qualitative statement of the law.

2. The slowest rate requires the same increment, within 0.1^{s}, by this as by the previous method. By the present method the other two rates require smaller increments, somewhat in proportion to the rates.

3. The proportional differences by the two methods do not point to any notable error in the previous method, but are a good expression for the difference in the mental attitude in the two methods.

The foregoing experiment was repeated five times upon the writer during as many successive days. The conditions differ in that I knew just what was going on physically except in one respect, namely, that I did not know whether the trial would be a regular or a control trial. In this series I do not record the result of the control trials because I set my standard so high that I made practically no error. The following conclusions may be drawn from the summary in Table VII.

1. The general direction of the rate-influence is the same as that found for the other observers.

2. There is a noticeable decrease in the rate-influence for the fastest rate during the progress of the experiment.

3. A reasonable expression for the difference in mental attitude due to my knowledge of the rate of change is found in the amount by which my threshold differs from that of the other observers.

VII. Effect of the rate of change upon the perception of very rapid increase in weight.

Apparatus E.

Very rapid rates of change being desired here, it was necessary to use a float of larger diameter, or nozzles allowing a more rapid stream to flow, than had hitherto been used. The former alternative was adopted, but with this alternative a change in the mechanism of the rest of the apparatus also became necessary. Apparatus *C* required that the operator should stop the increase when it had reached the desired height. The rates of change approaching the instantaneous, here required, could only be obtained by an automatic determination of the amount of increase by the apparatus itself. This was accomplished as follows:

Apparatus *C* was used in all its parts except three, namely: the float, the connection between the cell and the beam, and the rod which counter-

balanced the float. A light steel tube of 25^{mm} diameter was used for a float. The connection with the cell was reëstablished in the following manner. A balance beam E of the same dimensions as the balance beam A is placed immediately above A and parallel to it. We may name the float end of the original beam Af, and the corresponding end of the upper beam Ef and the other ends respectively Aw and Ew. Ef is vertically over Af and they are joined by two loops of fine wire which interlock at the middle in such a way that when the tension is released and Af and Ef approach each other the loops cause no friction and allow no spring or elasticity; the lower is fixed in an upright position and the upper falls vertically by its own weight. Now, following the same principle as in apparatus D, the standard weight is maintained by means of the compound balance action. The cell is attached to Ew and from the same point a balance pan (pan E) is suspended 400^{mm} below. In place of the rod at Aw another scale-pan (pan A) is suspended at the same distance as pan E. When the weight in pan E is equal to the weight of the float at zero the two beams stand in a horizontal position and the loops between Af and Ef are just on the point of making contact. A is balanced and exerts no influence on E, and E is balanced and exerts no influence upon the cell which, when lifted, has its own weight plus the weight of pan E. If the weight in pan A be diminished Af will pull on Ef by that amount and this will in turn lift at Ew, which lessens the weight of the cell by the same amount.

The balancing of the apparatus depends upon the position of the cell when lifted. A special support for the cell regulates this. It consists of a trap on top of the arm support (C_2). This is essentially a slat with one end hinged to the rear end of the arm support. Its front end is held up against an adjustable catch by a weight acting through a cord over a pulley. This cell is placed on the front end of this slat in the same lateral position as before, but it is supported at the standard height to which it should be lifted. When the cell is grasped it is held in the same comfortable position. The experimenter elevates the weight which supports the trap, the trap falls and leaves the cell supported by the hand in a definite position.

Let me further explain the apparatus by an illustration of how it works. Suppose I desire to produce a measured increase of 2^g on a standard of 40^g at a very rapid rate. The cell itself weighs 25^g and a weight is placed in pan E, so that the total weight of the cell when held in position, after the trap is dropped, will be 40^g. Both beams are balanced in a horizontal position and exert no influence on the cell. Then we take off 2^g from pan A. This makes Af pull on Ef

by 2^g and this in turn lifts the pan E by 2^g, reducing the standard to 38^g. This we correct by adding 2^g to pan E and again obtain our standard, 40^g. But now pan E is lifting 2^g at Ef and the same amount at Ew; if we then gradually restore the balance of A by immersing the float, E being stationary, the amount lifted at Ew will decrease until the zero point is reached and the contact between Af and Ef is broken. The contact is broken at the moment 2^g have been added to the weight of the cell making it 42^g. The rule determining the size of the increment is that the desired weight must be removed from pan A and placed in pan E. The rate of increase is determined by the size of the stream of water as before.

The above is an entirely satisfactory solution of the problem of how to produce quick and accurate changes of weight in a given standard without movement or jarring of the body lifted. The adjustment to the zero point may permit a possible error of $\pm\frac{1}{8}^g$. The trap holds the cell in the correct position, and, after a brief practice, the observer can retain this approximately, but for accidental movements of the hand there may be an error of within $\pm\frac{1}{2}^g$. There could be no other inaccuracy in the size of the increments, since they were made by actual interchange of gram weights.

The rates were timed by the graphic method of recording time. The recording pointer was placed in circuit with a means of making the circuit at the beginning of the increment and breaking it at the completion. The electric clamp key was used as in series I to make the circuit the moment the stream was let on. A platinum contact was built up at Af, such that Af rested upon it and kept the circuit closed as long as Af was heavier than Aw. The moment the beam A passed through its point of balance and the tension on the interlocking loops was released, Af left its contact and the electric current was interrupted.

I first measured the time of all the increments (the steps in the series differed by 2^g each) from 2^g to 20^g on one rate to find if the changes were uniform. This rate made the change at the rate of 1^g in 0.12^s. Taking the time to increase 20^g as a standard, and calculating the theoretical time for each increment, I found that the empirical results deviated from the theoretical only by an irregular fluctuation no larger than might be allowed for the error of measurement, i. e., there was no systematic error large enough to demand consideration here, and the increase may be considered as practically constant. Having found this I timed all the rates for the step of 20^g, and divided that up proportionately for the other steps. The rates adopted and measured in this manner are as follows:

	I.	II.	III.	IV.	V.
α	4.54	8.33	33.33	50.00	66.66
β	0.22	0.12	0.03	0.02	0.015
γ	0.11	0.21	0.83	1.21	1.54

Here α denotes the number of grams of increase per second, β the number of seconds to increase one gram, and γ the part of the initial stimulus per second.

Experiments.

The fastest rate hitherto used required the largest increment. Referring to the curves in Figure 3, what is the highest limit for these if they be continued to the left, and what form will they assume in returning to the low point that marks the instantaneous increase? This is the question I have tried to answer by the present series of experiments.

The quoted rates are within the limits of sufficiently accurate measurement by the present apparatus. The slowest connects with the fastest of the previous and the fastest approaches the instantaneous.

The method of minimum variation was here used somewhat differently from the previous manner. The threshold was determined five times for each rate as follows: the increments differed by 2^g each, but, in order to save time, five trials on each step were made in succession. A number of steps in the middle region were tried until a block of records was obtained in which the change had been perceived correctly every time in the largest of the increments tried and no time in the smallest. The few exceptions to this rule may be seen in the records from the fact that the highest number is less than five in those cases.

The observer was given a choice of two answers only, namely, "Change" or "No change." The merits and demerits of that limitation are well known. At a signal the observer grasped the cell with the hand in position to rest firmly. At a second signal the trap fell and he was to look for the differentiation which might begin about two seconds afterwards. He was required to give his answer as soon as the increment was completed.

The results for six observers are contained in Table VIII. The left hand section of the table shows the number of perceived changes out of five possible for each step. There the variation of any single increment may be traced for each observer. All but the first of the successive "5s" are omitted, and all increments above this are counted as perceptible in the respective single determinations of the threshold. Δ is found as before by taking the average of the single thresholds above

TABLE VIII.

Threshold of increase in a 40g weight at five rapid rates.

		2g	4g	6g	8g	10g	12g	14g	16g	ε	Δ	d
	I		1	5						0	4.8	0.8
	II			5	5	4	5			0	7.2	1.8
F. C.	III	1	3	3	5					0	5.0	1.8
	IV		3	4	5					0	5.2	1.4
	V	1	2	5						0	5.2	1.0
	I			1	2	0	5			0	12.0	0
	II						2	2	5	0	14.8	1.4
N. H.	III				3	2	2	5		0	12.4	1.6
	IV			1	4	5				0	9.2	1.0
	V			4	0	2	5			0	10.8	1.4
	I		1	1	3	3	4	3		0	12.4	2.0
	II		1	3	3	4	3	5		0	11.2	2.6
V. S.	III		1	4	5					0	6.0	0.8
	IV	3	3	4	4					1/4	6.4	2.0
	V		4	2	3	5				0	7.6	2.0
	I		2	2	5					1/3	6.9	1.4
	II		3	3	5					1/4	6.0	1.6
W. J.	III	4	4							1/2	2.8	1.4
	IV	3	5							1/2	2.8	1.0
	V	5	5							1/2	2.0	0
	I		2	2	3	2	3	3	5	0	14.0	1.6
	II		1	2	3	3	4			1/6	11.6	1.2
J. R.	III	4	4	3	5					1/4	4.4	2.8
	IV	4	2	4	4					1/4	5.2	2.6
	V	4	5							0	2.4	0.4
	I		3	3	5					2/4	5.6	2.0
	II				3	5				0	8.8	1.0
W. H.	III			2	1	2	5			0	11.2	1.0
	IV		1	2	2	5				0	9.2	1.0
	V	1	2	4	4	3	4			0	9.6	2.4
	I	0	30	47	77	90	87	100		3/27	9.3	3.5
	II	0	27	43	63	70	80	90	100	2/25	9.8	2.6
Av.	III	30	40	57	77	80	90	100		3/23	7.0	3.3
	IV	33	47	67	80	100				3/21	6.3	1.9
	V	37	60	83	90	83	97	100		1/25	6.3	3.1

Roman numerals, rates of change.

Figures at the top, increments in grams.

ε, the numerator gives the number of errors that were made in the number of control trials denoted by the denominator.

Δ, threshold.

d, mean variation: to find the mean variation for the series divide each by 2.2.

The average is stated as the percentage of the possible number of correct answers.

which all increments were perceived, on the supposition that, when an increment had been perceived every time, all steps above that would also be perceived. The assumption is quite valid, for the steps are larger and the successive steps would be taken under similar conditions with reference to the larger fluctuations in sensibility. The value of this threshold must also be estimated by its mean variation and by a comparison with the distribution of the figures in the first part of the table.

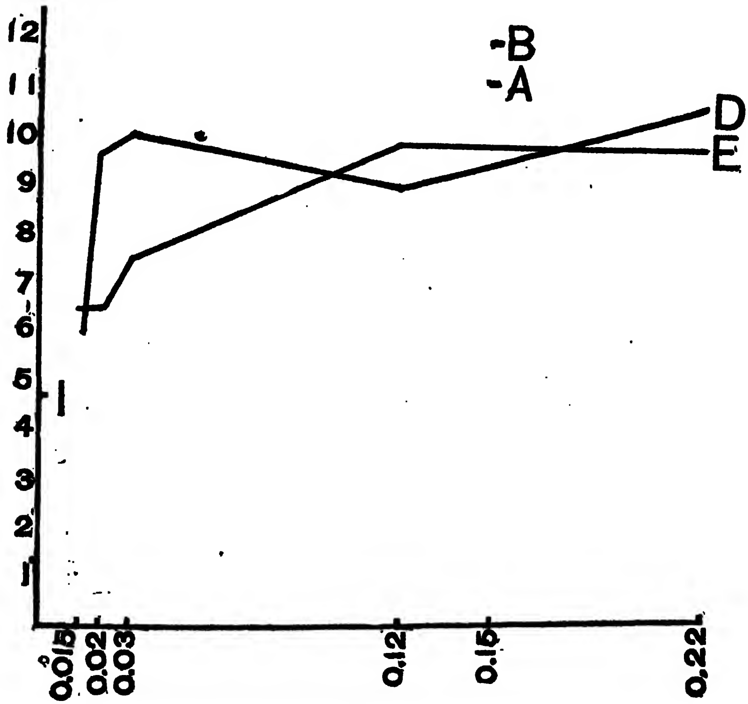


Fig. 4.

E, Results in Table VIII, p. 56.
D, Results in Table IX, p. 58.
I, Results in Table V, p. 46.
A, Highest point in *A*, Figure 3, p. 50.
B, Highest point in *B*, Figure 3.
The horizontal axis is divided on a scale 20 times as large as in Figure 3.

The number of experiments is too small to afford a detailed expression of the law of variation, but it is evident that we have found the maximum or turning point in the size of increments. The results as expressed in curve *E*, Figure 4, show the gradual return to the point of instantaneous increase. This curve shows their relation to the point *I* denoting instan-

taneous increase and the point *A* denoting the highest point in curve *A*, Figure 3, i. e., the threshold for the rate of 1^s in 0.15^s. The object of these experiments is to trace the connection between *H* and *I*. Since their relative distance is very much magnified in Figure 4, the scale in this figure should be compared with the scale in Figure 3.

The above experiment was repeated four times upon the writer, as far as possible under similar conditions. The results are expressed in Table IX and curve *D*, Figure 4.

Table IX.

Four experiments upon the writer; conditions similar to those in the preceding table.

		2^s	4^s	6^s	8^s	10^s	12^s	14^s	ε	Δ	d
A	I	2	2	4	5				¼	5.6	1.2
	II			2	5				⅓	7.2	1.0
	III			3	3	3	5		0	10.4	1.2
	IV	1	2	2	5				¼	6.8	1.4
	V	1	3	4	5				0	5.2	1.8
B	I				.2	4			⅓	9.6	1.2
	II				3	5			0	8.4	1.2
	III			1	2	5			0	9.2	1.0
	IV			5					0	6.0	0
	V		2	4					0	6.0	0.8
C	I				1	2	3	2	$\frac{1}{5}$	14.0	2.4
	II			1	1	5			0	9.6	0.4
	III			1	3	2	5		0	11.2	1.0
	IV			3	4	5			$\frac{2}{4}$	7.2	1.4
	V		4	4	4				$\frac{2}{4}$	6.0	2.2
D	I			2	2	4	3		0	14.0	1.6
	II			1	2	4	4		0	10.8	1.8
	III			2	3	3	5		0	9.2	2.2
	IV		1	3	4	4			¼	7.6	2.0
	V		2	3	5				0	6.4	1.2
Ave.	I	10	10	30	50	75	80	85	$\frac{3}{16}$	10.8	2.7
	II	0	0	20	55	95	95	100	$\frac{1}{14}$	9.0	1.2
	III	0	0	35	55	65	100		0	10.0	0.8
	IV	5	10	65	90	95	100		$\frac{4}{14}$	9.6	0.5
	V	5	55	75	95	100			$\frac{2}{15}$	5.9	0.4

Notation same as in Table VIII.

These results agree with the foregoing in that they show that the threshold is lowered as the point of instantaneous increase is approached.

In comparing the superposed curves in Figures 3 and 4 it must be remembered that there are important differences in the conditions upon which the results in each curve are based. Therefore, the comparison must not be one of absolute units, but of general directions and tenden-

cies. Thus, in Figure 3, the curves descend in a decided manner towards the right, and in Figure 4 they descend toward the left, though not with as great regularity. The curves in these two figures may be joined together and then they will express the general law stated in the next paragraph.

VIII. Some observations and conclusions.

The various conclusions in regard to the influence of the rate of change upon the threshold of change for pressure and muscle sense made under the conditions adopted in the above experiments may be generalized as follows: the threshold for the perception of difference in pressure and lifted weight rises rapidly from the threshold of instantaneous change and soon reaches a maximum from which it falls off gradually until the slowest rate at which the change can be perceived at all has been reached.

This is not an absolute law, but it is a well defined tendency. Its value depends largely upon the conformity of the above conditions of experiment to the normal conditions of our every-day experience. I have hoped to obtain the facts undistorted by using the so-called "unconscious" method and making the results partially statistical. I am not going to enter into any polemic with those who have found contradictory results (mainly Stratton), for, like other factors in our perception, the rate influence depends upon its relation to a number of unknown subjective and objective conditions which determine its nature and effect. The subject has just been opened for experiment.

Any law expressing the influence of the rate of change upon the perception of difference in sensory stimuli must be stated particularly with reference to the following among other factors:

1. The special sense organ. The law, derived from the above experiments, is indicative of relations that we find to obtain in other senses. Thus, there is a general agreement between these results and those found by Scripture and Stern on sight and by the same authors on sound (see references, p. 27), but there are important differences depending upon the functioning of the particular sense organs. The above may be made a general law of sensation, but it has definable peculiarities for each sense. Compare, e. g., Stern's results on sight and sound or mine on pressure and weight.

2. The kind of threshold. The rate influence has mainly been studied in the threshold of change. It is equally important and may be just as well studied in other thresholds, e. g., the threshold of sensation. I have made some experiments upon the least perceptible touch as depending upon the rate of impact of the stimulus. These experiments were made with a modified form of apparatus *A*. The rate influence was here more

marked than that for the threshold of difference in pressure, i. e., the largest stimulus was required near the instantaneous rate, which was much lower than for any gradual stimulus. At very slow rates the perception became very uncertain. Thus, I found it possible to apply a pressure of 4^g over an area only 1^{mm} in diameter upon a finger without the observer being able to detect it. I have made similar observations on the thresholds of sight and sound and on the thresholds of sensation, disagreeableness, and pain under electrical stimulation. These last experiments were made by an ordinary slide inductorium and a pair of electrodes. In such experiments the psychological method promises to be of great value for the study of the development of æsthetical ideas and tastes as depending upon the rate at which the sensory impressions are made, e. g., in approaching the threshold of pleasure or pain. And, what is mainly of theoretical interest in psychology has a very extensive practical interest for education.

HALL and DONALDSON and STERN (see references, p. 27) have studied the rate influences in the perception of motion by sight. I have found a marked variation in the perception of tactual and muscular space. It has been customary to take the rate variation into consideration in estimating lifted weights by requiring that the weights should always be lifted to the same height at the same rate. MÜLLER and SCHUMANN'S[1] measurements on this point are valuable.

I have constructed a dynamometer for measuring active pressure. A beam 300^{mm} long is supported upon pivot bearings at one end. The other end carries a pointer which moves over an arc graduated empirically from 0^g to 1000^g. The pointer end of the beam is supported by a steel spring of seventy coils hung vertically. The pressure point is a hard rubber disk 15^{mm} in diameter supported by a loop from a point on the beam 75^{mm} from the bearing end of the beam. This is a convenient and satisfactory dynamometer. In some experiments I required the observer to press to the standard, 500^g, and then reproduce it from memory at various rates of increase in pressure so as to reach the standard in the following times: (1) 2^s; (2) the observer's own time, generally about 5^s; (3) 5^s; (4) 10^s; (5) 15^s; (6) 20^s; (7) 25^s. The standard was pressed before each single trial; it was aimed to reach it in 5^s. The results show that the slower the pressure increases the more it is overestimated. The 2^s pressure is generally underestimated.

What is true for one unit applies also more or less to other units of measurement in sensation. I made some experiments, e. g., on the double

[1] MÜLLER AND SCHUMANN, *Ueber die psychologischen Grundlagen der Vergleichung gehobener Gewichte*, Archiv. f. d. ges. Physiol. (Pflüger), 1889 XLV 37.

stimulus in pressure with a standard of 5^s using apparatus *A* as in series I with rates I, II and V. The results for five observers were: I, 10.5^s; II, 12.1^s; and V, 13.4^s, i. e., the faster the increase the more the comparative pressure is underestimated. This is in accord with the laws found for dynamometry and for the threshold of pressure.

The rate influence is not limited to sensation. It enters our higher and more complex emotional and intellectual experience and activity.

3. The standard stimulus. The variation with the standard stimulus is, perhaps, best expressed by Weber's law.

4. The direction of change. For most stimuli there is a close relation between the threshold for increase and the threshold for decrease.

5. Method of marking the beginning and the end of change. Any method which leaves the reaction-time in the results is necessarily crude and the methods of elimination are uncertain. Introducing other methods changes fundamental factors in the conditions. STRATTON'S experiments and the mine have shown that the results depend to a great extent upon the method. According to STRATTON, the law may even be reversed. We may grant that possibility, but that does not detract from the value of our results, for each method reveals a characteristic tendency. It seems to me that STRATTON'S reversal of the law obtained by a gradation-method, is not due only to the change in method of recording the end of the increment, but to this in connection with other important factors, such as the special conditions of knowledge of the physical relations and the state of preparedness.

6. Knowledge of the facts. This changes the laws of perception in several ways. Knowledge of the physical facts acts as a suggestion. A conscious or unconscious distortion or correction is liable to creep in. The unconscious corrections are perhaps the most vitiating. Our ordinary experience affords us examples of change in which the physical processes are known and others in which they are not, and our experiences are different in the two cases. This is just what we find in experiment. From this point of view the cases in question must be stated with reference to (1) the state of expectancy or preparedness, (2) the distribution of attention, and (3) the degree of complexity of the discrimination. It is well known what a difference it makes whether a person knows what to expect and when and how to expect it. Such knowledge guides the distribution of attention. Thus, if I must distribute my attentive energy over 25^s it will be less potent at any moment of response than if it were sharply focused just for that moment. But on the other hand, during a prolonged uncertainty, expectation rises and the effort of attention becomes greater and greater.

WEBER'S LAW IN ILLUSIONS.

BY

C. E. SEASHORE, PH.D.

In a former article[1] I reported some measurements on illusions of weight. Since then it has occurred to me that we may not only measure an illusion, but also use this measurement as a means by which to determine some other mental factor whose relation to it is known. An experimental attempt at this subject revealed another problem which is involved in the first and, at the same time, affords a field in which the two may be solved together. This second problem, which, on account of the outcome of the experiments, proves to be the most important, is this: Does Weber's law depend upon the so-called real intensity or upon the apparent intensity of the stimulus?

As a most distinct and manageable case in which to carry on the investigation I selected the illusion of weight which is due to the knowledge of the size of the object lifted. The apparatus consisted of three pairs of cylinders (*A*, *B* and *C*) of the same weight, 80^g, and the same diameter, 37^{mm}; but of different lengths, *A* being 20^{mm}, *B* 120^{mm} and *C* 50^{mm}. The cylinders were made of polished hard rubber; in external appearance they were similar in all respects except length. The bottom plates were screwed in and could be removed by turning them three-fourths of a revolution by a key. A steel pin rose from the center of each bottom-plate for the purpose of receiving different weights consisting of circular disks with holes in the centers to fit this pin. There were two sets of these weights; one of 1^g to 15^g by one-gram steps and the other of 5^g to 40^g by five-gram steps. The adjustment of the weight by this method was suggested by Dr. MEUMANN, of Leipzig. It is a modification of Professor JASTROW's muscle sense apparatus.[2]

Twenty students in experimental psychology were examined and asked to give their judgments regarding the heaviness of the weights but to make no correction, allowance, or guess, based upon knowledge of the

---

[1] SEASHORE, *Measurements of illusions and hallucinations in normal life*, Stud. Yale Psych. Lab., 1895 III 1.

[2] I am under obligations to Professor BLISS for facilities and suggestions, and to members of his class in the New York University summer school, 1896, for assistance as observers in the present experiments.

illusion involved. As has been proven (pages 5–9 in my investigation cited above) the illusion of weight persists, but is not so strong when the fact of the illusion is known; therefore, observers who are aware of the illusion and those who are not aware of it fall into two distinct classes. In the present experiments even the details of the illusions of weight and of this illusion in particular were demonstrated before the observers until all were conversant with the facts in question. Therefore, the illusion here measured is not the maximum. The preparatory demonstration was, however, made by a different set of cylinders in which the diameters varied so that none of the observers knew the exact extent of the illusion in the present apparatus.

The aim was to determine two classes of facts: (1) the threshold, or least perceptible difference, for each pair of cylinders, and (2) the amount and kind of illusion in *A* and *B* respectively when measured by *C* as a standard. The first was determined by the following method: The weights in the continuous series rising by one gram each step were tried until three successive increments had been correctly perceived. The lowest of these was considered a threshold value. The observers were allowed to answer "equal" or "different" and, in the latter case, they were required to point out the heavier. The amount of the illusion was found by determining how much the weight in the *C* cylinder had to be varied from the standard in order to make it equal to the *A* cylinder. The same procedure was repeated for the *B* cylinder. The series of weights which differed by five-gram steps were used in the measurement of the illusion.

The results are given in the Table. One determination was made in the order ΔA, ΔB, ΔC, K, K' of which the results are recorded in the *a*-columns. Then the series was repeated in the reverse order with another complete determination on each point. These results are recorded in the *b*-columns. For the threshold *a* and *b* have the same value, but in the illusion-measurements *a* represents the lowest difference which made these two cylinders apparently equal, and *b* the highest; i. e., in *a* I started from the point of physical equality and continued to the first point of subjective or apparent equality, while in *b* I started with an excessive difference and decreased this until the upper limit of apparent equality was reached.

The experimenter handed the cylinders from behind a screen by pairs, placing them on end side by side in a convenient position upon a baize-covered table. The observer was required to grasp them as nearly as possible in the same manner and lift them always to the same height with the same speed. He was also required to keep them as near to-

gether as possible, and, after having tried them back and forth, to interchange them in position and again compare them in both directions, continuing as long as he thought profitable. Thus the errors of time, speed, place, fatigue, practice, surprise, temperature and order were fairly eliminated.

Subject.	ΔA *a*	ΔA *b*	ΔA *E*	ΔB *a*	ΔB *b*	ΔB *E*	ΔC *a*	ΔC *b*	ΔC *E*	*K* *a*	*K* *b*	*K′* *a*	*K′* *b*
I	4	1	$\frac{1}{9}$	4	3	$\frac{0}{11}$	1	2	$\frac{0}{7}$	10	20	10	20
II	5	3	$\frac{1}{12}$	7	5	$\frac{1}{16}$	4	4	$\frac{1}{12}$	15	15	20	15
III	3	2	$\frac{3}{9}$	3	2	$\frac{0}{9}$	1	2	$\frac{0}{9}$	15	15	15	15
IV	2	1	$\frac{1}{7}$	1	4	$\frac{0}{9}$	1	8	$\frac{0}{13}$	20	25	10	20
V	2	4	$\frac{2}{10}$	3	4	$\frac{0}{11}$	3	1	$\frac{1}{8}$	0	0	10	5
VI	1	1	$\frac{0}{8}$	3	1	$\frac{0}{8}$	3	3	$\frac{0}{10}$	20	20	15	15
VII	3	6	$\frac{3}{13}$	4	6	$\frac{0}{14}$	4	6	$\frac{2}{14}$	10	20	15	15
VIII	4	2	$\frac{0}{10}$	3	3	$\frac{0}{10}$	2	2	$\frac{0}{8}$	20	10	15	15
IX	1	2	$\frac{1}{7}$	6	2	$\frac{2}{12}$	2	7	$\frac{2}{13}$	15	10	10	5
X	3	4	$\frac{0}{11}$	5	8	$\frac{0}{17}$	6	9	$\frac{0}{19}$	20	25	10	20
XI	1	2	$\frac{0}{7}$	3	2	$\frac{0}{9}$	1	1	$\frac{0}{8}$	15	15	15	15
XII	3	1	$\frac{1}{8}$	4	4	$\frac{4}{12}$	3	3	$\frac{3}{10}$	15	10	5	5
XIII	3	3	$\frac{4}{10}$	1	6	$\frac{2}{11}$	3	4	$\frac{2}{11}$	20	15	0	5
XIV	2	2	$\frac{0}{8}$	2	2	$\frac{0}{8}$	3	1	$\frac{1}{8}$	25	25	10	15
XV	1	2	$\frac{1}{7}$	2	7	$\frac{2}{13}$	1	5	$\frac{1}{10}$	15	10	−5	5
XVI	7	1	$\frac{0}{12}$	7	5	$\frac{0}{16}$	2	4	$\frac{1}{10}$	10	20	10	5
XVII	1	2	$\frac{0}{7}$	1	2	$\frac{0}{7}$	3	3	$\frac{2}{10}$	15	20	15	20
XVIII	5	7	$\frac{0}{16}$	6	8	$\frac{0}{15}$	4	5	$\frac{0}{13}$	5	10	10	5
XIX	3	2	$\frac{0}{9}$	6	8	$\frac{1}{15}$	3	2	$\frac{0}{9}$	15	25	15	20
XX	3	6	$\frac{0}{13}$	2	7	$\frac{0}{13}$	4	9	$\frac{0}{17}$	10	25	20	20
A	2.9	2.7	$\frac{0.9}{9.6}$	3.6	4.4	$\frac{0.6}{12.1}$	2.7	3.9	$\frac{0.8}{10.9}$	14.5	17.2	11.2	13.0
d	1.1	1.3		1.4	1.7		1.1	2.0		4.2	5.5	4.4	5.6
M	2.8			4.0			3.3			15.8		12.1	
m	1.2			1.5			1.5			4.8		5.0	

The unit of measure is the gram.

ΔA, ΔB, ΔC, the thresholds for the respective pairs.

K, overestimation of *A* when measured by *C*.

K′, underestimation of *B* when measured by *C*.

a, the first measurement.

b, the second measurement.

E, the proportion of errors made; the numerator expresses the number of so-called wrong judgments made out of the total number expressed by the denominator.

A, average; *M*, the mean of the two averages.

d, mean variation; *m*, the mean of the two mean variations. The mean variation for the series may be found by dividing these by 6.3.

The necessity of retaining the same standard throughout the entire experiment was urged upon each observer. The standard of sureness can be seen to some extent in the individual records by comparing the number of errors with the size of the increments. E shows the number of actual errors in comparison with the number of possible errors, or the total number of judgments that were made. The comparatively small number of errors in B may be accounted for partially by the favorable position of B in the order of trials. The b-trials in C were often disturbed by their proximity to the illusion-trials, and A was subject to still more disturbance because of its position as the extreme first and last trials. I call these so-called wrong judgments "errors" in a different sense from that in which the illusions are called errors. The illusions are normal, but what is here called an error is not based upon any such constant factor that is known.

The variation is apparently large, but it must be remembered that it is the individual variation of twenty different observers from their average and that the number of trials on each observer is small. The general agreement of so many is worth more than the consistency of one in a larger number of trials. If we consider the uniformity of the conditions of the observers, subjective as well as objective, we find ourselves justified in taking the averages of these twenty (in all, forty complete determinations on each point) as a fair expression of the answer to the two original questions.

Does Weber's law depend upon the real or upon the apparent weights? If upon the apparent, is there any traceable law? In the present case A is overestimated by 15.8^g and seems to weigh 95.8^g in terms of C which we assume as a standard and common measure. According to that a physical change of, e. g., 3.3^g in A will appear as a change of

$$\frac{95.8}{80} \times 3.3 = 4.0.$$

On the other hand B is underestimated by 12.1^g and appears to weigh 67.9^g in terms of C. Then a physical change of the same amount, 3.3^g, in B will appear as a change of $\frac{67.9}{80} \times 3.3 = 2.8$. There is a coincidence between this theoretical consideration and the above results, but we must seek other relations in the results in order to get a more direct answer.

The ratios for the relation between the respective thresholds and the standard for these particular conditions are:

$$\Delta B = \tfrac{1}{20}, \quad \Delta C = \tfrac{1}{24} \text{ and } \Delta A = \tfrac{1}{29}.$$

These are the constant multiples which would express Weber's law for the same conditions if the measurements were repeated with any standard weight within the limits in which the law is applicable. These are, however, only representative of a large number of possible illusions. As I have proved (pp. 3–5 in the article cited above) within certain limits, the illusion varies directly with the difference in size. We might have made the illusion stronger by making A smaller and B larger, or by obtaining the naïve, "unconcious" judgment of the observers. In such a case we should have gotten a number of thresholds outside of the present extremes. Similarly we might have decreased the illusion down to zero. It is evident then that if we state that Weber's law requires, e. g., $\frac{1}{24}$ of the standard to produce a just noticeable increment on 80^g we have stated it only for one particular relation between the standard weight and the size of the object. Grant that C is the nearest approach that we can get toward freedom from this one illusion, then the relation of the threshold to this would denote that which is generally expressed by Weber's law. But a large number of conditions, represented by A and B are just as important from a practical point of view, for it is very rare in normal life that we lift objects that give us no illusion. This was preëminently true in the classic experiments on Weber's law. Now, the facts known about the regularity and trend of this illusion justify us in assuming that, if the same proportions between the sizes and the standard weight be retained, the illusion will approach a constant fraction of the standard within the limits of the validity of Weber's law. Therefore, if we had determined the threshold empirically under all possible degrees of illusions like the one under discussion, Weber's law might be expressed for all standard weights within the above assumed limits by as many fractions, like $\frac{1}{24}$, as there are illusory effects such as A and B represent. The fact of this possibility implies an affirmative reply to our first inquiry, namely, that we can use the measurement of one mental characteristic as an index to another; in this case the measured illusion is an index to the threshold. An attempt to state it from such a complexity of conditions might seem hopeless, but the above results give us a key.

First, all overestimation lowers the threshold and all underestimation raises it. Secondly, retaining the notation of the Table, we may formulate the results thus:

$$\frac{\Delta A}{\Delta C} = \frac{C - K}{C}$$

and

$$\frac{\Delta B}{\Delta C} = \frac{C + K'}{C}.$$

The error involved by substituting the empirical results is 5% in the first equation and 10% in the second. Both these, it may be seen from the table, are less than the respective mean variations. Disregarding the illusion (K and K' in the above formulas) as has always been done, the error in substitution would be 15% in the first and 21% in the second equation. Hence Weber's law stands in a much closer relation to the apparent weight than to the physical standard.

If we know the increment needed for an object of a given weight and size, e. g., C, at any standard, and know the amount of the illusion for all differences in size in objects of this weight, we may be able to calculate the threshold of perceptible difference for all such cases. For

$$\frac{\Delta A}{C-K} = \frac{1}{28}$$

$$\frac{\Delta B}{C+K'} = \frac{1}{28}$$

and

$$\frac{\Delta C}{C} = \frac{1}{24}$$

These give a constant fraction for all the equations, in this case approximately $\frac{1}{28}$. This fraction may be supposed to hold as a constant for all conditions, of which the above A, B and C are representative. Hence, we may state the principle for the dependence of Weber's law upon apparent weight, as

$$\frac{\Delta E}{S+K} = M$$

where ΔE is the threshold of perceptible difference, S the physical standard weight, K the amount of the illusion (which must retain its sign + or — according as it is underestimation or overestimation of the standard), and M a constant.

A question may here be raised as to the reason for and effect of choosing C of this particular size. It was chosen, after some preliminary experiments, because it seemed to correspond fairly to the size that the adopted standard weight might suggest. What would have been the effect of making it larger or smaller than this? It may be possible to detect some law for the dependence of the illusion upon this, but at the present stage of measurements in illusions this factor is negligible and the standard may be chosen of any size which is not so extreme as to introduce other sources of error, such as difficulty in grasping, provided the results are stated in terms of that size. Such results may also be convertible into

terms of each other, for on this theory we may add the illusion of A to the illusion of B and take the sum of these as the expression of the illusion of either A or B in terms of the other. Thus

$$\frac{\varDelta A}{\varDelta B}=\frac{B-(K+K')}{B}$$

and $$\frac{\varDelta B}{\varDelta A}=\frac{A+(K+K')}{A}.$$

The error involved by substituting the actual figures is 5% for the first equation and 7% for the second. Although these are extreme cases the error of the substitution is no greater than that found when the mean, C, was used as a standard. Therefore, within obvious limits, we are justified in choosing the standard of any convenient size in measurements like these.

Just as no one now claims an exact mathematical conformity for Weber's law in any sense, we must construe the above formula liberally. There may be some more determinable factors that must be taken into it; we can never hope to determine and control all such factors. Judgments as to the validity of the law have heretofore been made largely upon experiments that involved the illusion here discussed, or similar ones, and the variations caused by them have been counted as discrepancies in the law. The above data at least justify us in assuming this relation of Weber's law to illusions as a working hypothesis. It promises not only the same degree of comformity as the law has had on the old theory, but also an extension of it both in the degree of conformity and the range of its applicability.

RESEARCHES ON VOLUNTARY EFFORT.

BY

E. W. Scripture.

We may suppose that in primitive times quantities were measured according to mental scales; thus distances would be established by the eye or paced off by walking, weights would be judged by the effort required to lift them, etc. In most cases later civilization has, by the method of maximum agreement,[1] established successively finer methods wherein the disagreements due to the personal and instrumental differences are reduced to extremely small quantities. These are the so-called "physical" or "instrumental" methods. Thus by instrumental methods a scale for space is developed from the standard meter bar, or a scale of mass from the standard kilogram. With such scales in our possession the problem arises: how do our mental scales compare with the instrumental ones? The solution of this problem in regard to the voluntary efforts used in compressing the fingers was attempted in the following way.

Apparatus.

The dynamometer. Experience with various dynamometers led to the construction of a new one. Two spring-steel rods are inserted into a brass block so that they extend from one side. Flat hard-rubber knobs are fastened at the appropriate distance from the block; when pressure is applied to these knobs, the rods bend inward after the manner of sheep-shears. A light plate is attached to the end of one rod; the end of the other rod is pointed to serve as an index. The amount of the pressure exerted on the knobs is measured by the deflection of the rods, and this is indicated by the distance through which the index passes over the plate. The physical scale is established by resting the dynamometer on one knob and placing weights on the other knob; the position of the index for each weight is scratched on the plate. The knobs may be placed at any desired point along the rods. As they are placed nearer to the block, the apparatus becomes less sensitive and the movement less; as they are moved toward the ends of the rods, the apparatus becomes more sensitive. In the present investigation they are so placed that the maximum force usually exerted makes the index pass over the entire scale.

[1] Scripture, New Psychology, ch. III, London, 1897.

The instrument is graduated for one position of the knobs and must then be left unaltered. These dynamometers are so readily made that it is preferable to have a separate one for any special problem rather than to alter the knobs and change the scale.

The dynamometer is used by holding it up between the ends of the thumb and one of the fingers. The other fingers are kept away from the one used. The metal block may be allowed to rest lightly on the palm of the hand.[1]

The dynamograph. The dynamometer is turned into a dynamograph by means of a piston recorder or a recording capsule. The particular one used in the following experiments was made by fastening one of the extra glass cylinders of a HÜRTHLE piston recorder to one of the steel rods while the piston was fastened to the other rod. Pressure on the knobs caused the piston to descend in the cylinder and the air to pass through the rubber tube to the recorder. The cylinder is adjustable to any point on the rods; this regulates the amount of movement in the piston.

The recording point is rested against any smoked surface in the usual way. It repeats the movement of the piston on the dynamometer and consequently indicates the pressure exerted. To graduate the record the dynamometer is placed in a vise or a clamp and is subjected to pressure so that its index reads 1, 2, 3, etc. on the scale; the position of the recording point at each of these readings is marked on the smoked surface.

SCALE FOR THE THUMB AND FINGER.

Two points are to be determined for our scale of voluntary effort: 1, the relation of its units to the weight units; 2, its regularity.

The subject of the experiment takes the dynamometer in his hand. At the command "One" he exerts a light pressure; at the command "Two" a pressure intended to be twice as great; at "Three" three times as great; etc. At each pressure the recording point marks its excursion on the smoked surface; between records the surface is moved so as to keep the marks separate. The experiment is repeated several times. Then the dynamometer is placed in the vise, which is screwed up until the index indicates a pressure of 1^{kg}; a turn of the drum inscribes the line for 1^{kg} on all records. This is repeated for 2^{kg}, etc. The records are then read in tenths of a kilogram.

[1] This dynamometer and the dynamograph are pictured in SCRIPTURE, New Psychology, Figures 4 and 24, London, 1897.

The following is a specimen record; the figures in the top line give the relative intensities of the efforts as intended, while the actual results of five experiments are recorded below them. The unit is the kilogram.

1	2	3	4
0.5	1.0	1.7	3.3
0.4	1.0	1.6	2.8
0.5	1.0	1.6	2.5
0.8	1.6	2.5	3.7
0.9	2.1	3.2	4.1

The question arises concerning the proper method for computing the results. If the values in each column represent identical processes, they should be added directly. This is the method which I have followed in reporting the results in the New Psychology (p. 218). Further consideration leads me to modify the procedure. The values for effort 1 are not intended to be one particular effort, but any convenient light effort to start with. Likewise the values for effort 2 are not attempts at a certain definite effort, but are attempts to double effort 1, which may be different for different experiments, etc. The proper procedure seems, therefore, to lie in measuring efforts 2, 3 and 4 by effort 1, as a unit; this is done by dividing all four records by the record for effort 1 in each experiment separately. The specimen record then takes on the following form:

2	3	4
2.0	3.4	6.6
2.5	4.0	7.0
2.0	3.2	5.0
2.0	3.1	4.6
2.3	3.6	4.6

The averages and mean variations are then computed in the usual way. The results for several observers are given in the following table:

TABLE I.

Subject.	1	d_1	2	d_2	3	d_3	4	d_4	n
I	1	29%	2.1	9%	3.5	7%	5.6	2%	5
II	1	14%	2.0	11%	3.3	21%	7.1	19%	5
III	1	25%	3.0	27%	5.7	33%	11.4	14%	4
IV	1	22%	2.2	14%	3.1	29%	4.6	24%	4

d_1, d_2, d_3, d_4, mean variations. n, number of experiments.

Scale for forearm and hand.

These experiments were made with a dynamometer constructed by Dr. Seashore (p. 60, above). A light wooden rod was hinged at one end to an upright; a coiled spring supported the rod in a horizonal position. Pressure on the rod at a given point deflected it downward; this point was chosen very near to the axis in order to make the movement a minimum. An index at the movable end of the rod passed over an arc graduated in grams.

The subject was seated with the hand and arm extended horizontally. At the signals he executed downward pressures intended to be in the relations of 1, 2 and 4. The results are given in the following table. The experiments were all made by me on Dr. Seashore on the same day in successive groups.

Table II.

	1	d_1	2	d_2	4	d_4	n
	1	12%	2.2	9%	3.8	11%	10
	1	17%	2.3	24%	3.9	23%	10
	1	23%	2.4	13%	4.2	17%	10
	1	26%	2.3	20%	4.1	28%	10
	1	19%	2.1	15%	3.3	14%	10
Mean	1	19%	2.3	16%	3.9	21%	50

d_1, d_2, d_4, mean variations. | n, number of experiments.

Conclusions concerning the scales.

The mental scale of exertion is a fairly definite affair. It varies considerably in different individuals, but is fairly constant for the same individual on a given occasion.

The question of how these scales are established by past experience is not touched upon; the problem for the experiments related to the actually existing scale.

Repeated voluntary efforts.

(Henry E. McDermott.)

The purpose of these experiments was to measure, not the fatigue of maximum pressure, but the fatigue resulting from many repetitions of a moderate pressure, thus showing the fatigue of the finger muscles under control of the will involving concentrated attention.

The instrument used was the dynamometer described above (p. 69).

The first person experimented on, A. G., was a High School student. I allowed him to give a desired pressure and then told him to relax the grip, and with the eyes closed to give the same pressure as before. His results expressed in dekagrams were as follows: 78, 75, 80, 76, 85, 85, 85, 85, 83, 80, 84, 85, 90, 85, 85, 86, 82, 85, 80, 83, 83, 83, 84, 84, 85, 86, 90, 89, 90, 90, 90.

At 90 the pointer touched the extreme of the scale and continued to do so for several seconds. In this set we see a tendency to gradually increase the grip as it is repeated; this is exactly the opposite of what was expected. The results fluctuate for a time and then for a few seconds become regular. On the average, however, they slowly, yet constantly, increase in strength.

The second person experimented on was also a High School student, F. C. His results were 55, 70, 65, 70, 70, 75, 74, 76, 80, 80, 80, 82, 74, 80, 83, 82, 86, 85, 85, 85, 85, 83, 84, 82, 81, 78, 82, 85, 86, 83, 80, 82, 82, 83, 83, 82, 83, 85, 85, 81, 76, 77, 79, 80, 80, 73, 74, 75, 80, 78, 80, 80, 85, 90, 90, 88, 90, 88, 90, 90, 90, 90, 90, 90, 90, 90, 88, 89, 90, 90, 85, 89, 89, 88, 88, 90, 90, 90. In this set we see nothing very different from the first, except that there was greater regularity at the start and that the difference between beginning and end was greater because the starting point was lower.

The third person experimented on was also a High School student, N. B. His results were, 30, 34, 32, 33, 32, 29, 32, 29, 30, 30, 32, 30, 34, 33, 31, 29, 29, 29, 29, 31, 31, 32, 29, 33, 35, 32, 35, 40, 45, 35, 39, 38, 40, 38, 39, 41, 40, 36, 32, 40, 40, 35, 36, 34, 30, 38, 35, 35, 35, 35, 36, 34, 36, 40, 40, 35, 40, 40, 42, 40, 39, 40, 50, 50, 48, 45, 50, 50, 48, 44, 45, 44, 40, 40, 43, 44, 45, 44, 41, 40. In this set we have a remarkable constancy of exertion. However, the tendency to increase is noticeable, as almost all the later results are greater than earlier ones. The greatest difference is 20, in contrast with 26 of A. G. and 35 of F. C.; both of which would have been even greater had the scale been longer.

The fourth subject was a college student, J. R. N. His results were 47, 55, 50, 51, 55, 60, 62, 56, 60, 64, 66, 65, 71, 65, 72, 68, 68, 70, 66, 65, 68, 75, 76. In this set we have an almost constant increase up to a maximum of 29, which is large considering the shortness of the experiment.

The fifth subject was D. J. R., a carpenter. His results were 55, 53, 54, 65, 66, 68, 65, 66, 77, 75, 73, 72, 78, 78, 80, 82, 85, 85, 87, 85, 82, 83, 80, 82, 81, 85, 87, 90, 85, 87, 90, 90, 90, 90. At 90 the

NEW APPARATUS AND METHODS.

BY

E. W. SCRIPTURE.

Those pieces of apparatus which have been developed for purposes of research have been in general described in connection with the investigations for which they were first used. There remain two classes of apparatus for special description. The first class is that of general utility for all purposes; the second that for demonstration purposes. Both classes are largely the effects of the increased numbers of students, whereby it becomes necessary to provide labor-saving utility-pieces and practicable means for demonstrations on a large scale.

LAMP BATTERIES.

Long experience with galvanic and storage batteries of many sorts made it evident that some method must be devised by which the city current could be made available for all the battery work of the laboratory. As the Yale laboratory is supplied with the 110-volt direct current, the problem was reduced to that of finding a method of readily transforming it at any point in the building to a current of lower voltage.

A motor-dynamo, or motor-transformer, was considered. This machine is attached to the supply wires at any point; two wires leading from it furnish the current at the particular voltage for which the machine was built. It is, however, quite costly and also inconveniently heavy. A laboratory of any size can hardly do with an equipment of less than ten batteries; such a set of motor-dynamos would be quite beyond the reach of most institutions. A larger motor-dynamo might be used to distribute a low-voltage current throughout the laboratory by a special set of wires. This method is open to many objections; it need not be considered when the laboratory receives the 110-volt direct current, as the lamp batteries offer a better solution. When, however, an alternating current or one of very high voltage is received, the proper method would presumably be to transform it to a direct one of 25 volts and send it through the laboratory to be used from sockets by means of the appropriate lamp batteries.

It was suggested by Prof. A. WRIGHT, of the Physical Laboratory, that a shunt arrangement might be made by means of lamps in such a manner as to yield a current of the desired amount and tension. This was tried,

but owing to the lack of lamps suitable for the shunt, a coil of wire was used.[1] The arrangement was fairly successful, but was finally abandoned. A study of catalogues of incandescent lamps showed that the original idea was a possible one; thus the lamp battery was finally developed.

The principle of the lamp battery may be explained by describing the method of construction. A convenient form of battery is made as follows: A base-board 10 x 6 inches (say 25 x 15 centimeters) is sawed from a board 1 inch (2½ centimeters) thick. It is convenient to keep a supply of such bases varnished and ready for use, as an extra battery may be

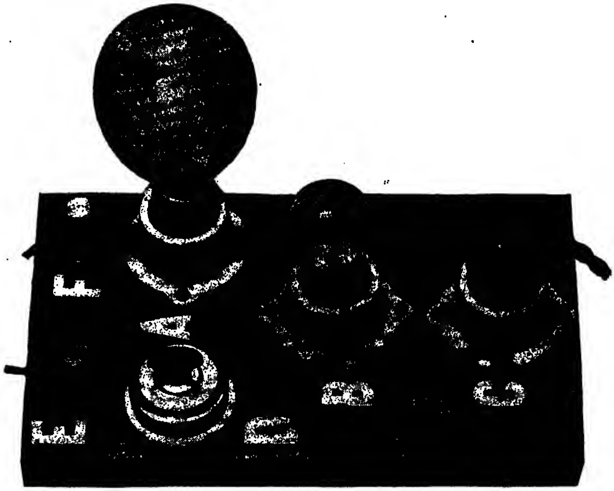


FIG. 6.

required at any time. Three lamp sockets (so-called "wall receptacles") a snap switch and two binding-posts are then screwed to the board in the positions indicated in Figure 6. Socket *A* is for lamps with the same base as that used on the regular supply circuit for lighting the building; sockets *B* and *C* are for lamps with a different base. For example, I use the T-H base for *A* and the Edison base for *B* and *C*. Thus it is impossible to place a lamp in the socket not intended for it. The battery is wired with the usual silk-covered lamp cord, the ends being neatly tied with thread. The method of wiring is sufficiently indicated in the figure. A supply of plug wires is prepared. What I call a "plug wire," for lack of a better term, is made by connecting the ends of an ordinary

[1] SCRIPTURE, *Some new apparatus*, Stud. Yale Psych. Lab., 1895 III 109.

lamp cord (6 feet, or 2 meters) to a socket plug; the other ends are scraped, bound with thread and left free.

To use the battery a plug wire is inserted in any lamp socket on the supply circuit. The free ends are brought to the binding-posts *E* and *F*. A 110-volt lamp of the required ampèrage is placed in *A*. Thus for an electric fork a 1-ampère lamp will be used, for a spark coil a 4-ampère lamp, etc. A low voltage lamp of the same or greater ampèrage than the one in *A* is inserted in *B*. Thus for the electric fork the lamp must carry at least 1 ampère in order to correspond with the lamp in *A*; it may conveniently be of 10 volts. For the spark coil a lamp of 8 volts 4 ampères would be suitable.

A plug wire is now placed in *C*, and the switch *D* is snapped to turn the current on. At the ends of the wires from the plug in *C* a current can now be drawn whose maximum intensity is practically the same as that in the lamp *A* and whose tension is practically the same as that at the poles of the lamp *B*. In the case of the electric fork it would be a current of 10 volts 1 ampère; for the spark coil it would be 8 volts 4 ampères.

The lamp battery behaves like any other battery. Increased resistance in the external current decreases the intensity of the current delivered, etc. For circuits of great resistance a lamp of higher voltage may be used in *B*. For larger currents than 4 ampères the sockets at *A* and *B* are doubled, as it is not advisable to use the ordinary socket for a current of more than 4 ampères on a 110-volt circuit.

The character of the lamp batteries can be seen from the following tables.

TABLE I.

Lamps used in the batteries.

LARGE LAMPS.

Mark on Lamp.	Trade Name.			
A	110 volts	100 c. p.	4	ampères.
B	110 volts	100 c. p.	3½	ampères.
C	110 volts	64 c. p.		
D	110 volts	32 c. p.		
E	110 volts	16 c. p.		
F	110 volts	8 c. p.		

SMALL LAMPS.

Mark on Lamp.	Trade Name.		
m	8 volts	4	ampères
n	8 volts	4	ampères
o	8 volts	4	ampères
p	12 volts	3	ampères
q	12 volts	2	ampères
r	12 volts	1	ampère.
s	12 volts	0.7	ampère.
t	10 volts	1	ampère.
u	6 volts	1	ampère.
v	20 volts	16	c. p.

TABLE II.

Results of various combinations of lamps.

Lamps used.	Am	An	Ao	Bm	Bn	Bo	Bv	Cm	Cn	Co	Cp	Cq	Cv
Potential in volts.	9	5	7	7	5	6	37	4	3	4	7	10	25
Max. cur. in amp.	4.0	4.0	4.0	3.5	3.5	3.5	3.5	1.9	1.9	1.9	1.9	1.9	1.9

Lamps used.	Dp	Dq	Dr	Dt	Du	Dv	Eq	Er	Es	Et	Eu	Ev	Fs	Fv
Potential in volts.	4	5	11	10	5	15	3	5	7	4	2	8	4	6
Max. cur. in amp.	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.5	0.5	0.5	0.5	0.5	0.3	0.3

As it is sometimes desirable to distinguish the poles of the battery, the left hand wire has a red covering, while the right hand wire has a green one, and all the sockets are so placed that the central contact is connected with the red wire. For the plug wires I use a twisted red and green cord, with the red cord connected to the central contact. All sockets on the supply wires have the central contact connected with the positive wire. Thus all central contacts and all red wires are positive.

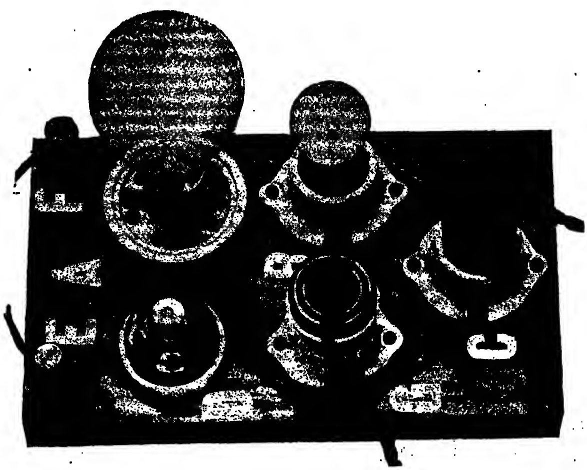


FIG. 7.

Some of the lamp batteries are wired in a slightly different manner. The purpose of the new wiring is to render it possible to use two circuits in parallel. For example, to run a DEPREZ marker with a 100 v. d. electric fork, having a low resistance magnet, the fork should not be placed in series with the marker as the current running through the fork would be greatly reduced by the high resistance of the marker. The proper way is to run the wires from the battery to the marker and then

place the fork as a shunt around the marker. Every time the fork makes contact the current pulls the prongs but is shunted from the marker because the fork offers so much less resistance, whereas at every break of contact the current is forced through the marker. Thus a large current may be used for the fork and a small one for the marker. This method of connection may be arranged with the lamp battery just as with other batteries, but a further improvement may be made. A fourth socket, *G*, is placed in series with the socket for the small lamp, as shown in Figure 7. The lamps are arranged as before; the plug wire from *C* is connected with the fork and another plug wire from *G* with the marker. The battery runs the fork as usual. Every contact of the fork shunts the current from *B* and *G*; every break of the fork, however, forces the current at a tension of 110 volts through the marker. The advantage of this arrangement is frequently very great. This form of battery may be conveniently termed the "extra circuit battery." By closing *G* with a metal plug the battery may be changed to the same system as Figure 6.

To save time and space I mount several lamp batteries on a single board and fasten it on the wall where it is likely to be used. Figure 8 shows such a battery board placed over the drum-table in the time-room. The switch at the top turns off the current completely; the socket in the middle gives direct access to the 110-volt supply, e. g., for running a motor. From the fuse block at the bottom the wires divide to the four batteries, each battery having its separate switch. Two of the batteries are wired by the method shown in Figure 6. The first and third, counting from the left, are wired after Figure 7; the plugs for closing the extra sockets hang at the sides when not in use. The extra switch introduced in the latter batteries enables further changes, but the arrangement is too complicated for ordinary use. The cost of a lamp battery is much less than that of a corresponding galvanic battery; the expense of running it on the city circuit is trifling; the only renewals are those of the lamp when it is burned out; a new battery can be made in ten minutes; the saving of time formerly required for setting up or replenishing batteries is worthy of consideration.

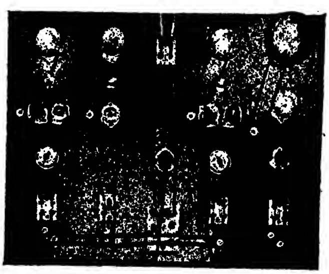


Fig. 8.

Multiple key.

The multiple key described in the first number of these Studies (pp.

10, 97) has undergone further improvement. In addition to changes in execution such as greater lightness of the parts and fineness of workmanship, the following important alterations have been made. 1. Another break contact has been added to the rear end of the lower lever; thus two circuits can be broken simultaneously by pressure on the key, with or without closing one or two other circuits at the same movement. This double break is not only very useful on many occasions, but is sometimes indispensable. 2. The point which dips into the mercury cup has been made adjustable. 3. The main contacts are independent; this re-

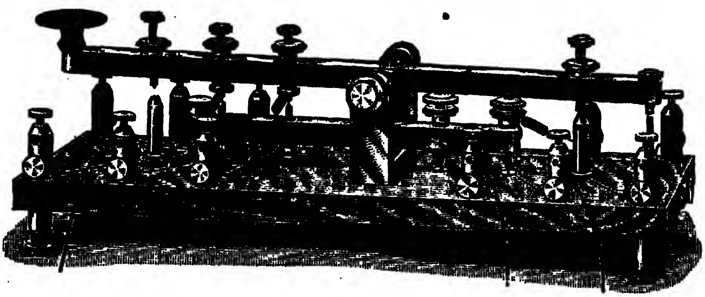


FIG. 19.

quires twelve binding posts. 4. All connections are made on top so as to be directly visible. The system of connection can be seen in Figure 19. The wire from the further post on the front of the key leads to the mercury cup which is hidden by the third post from the left in front in the figure.

In this connection it may be well to mention that, when this key (or any other key) is used with the spark coil, the condenser should be connected around the place where the circuit is broken. The spark coil should have a separable condenser. When a coil is to be bought, it may be ordered to be built in three separate pieces; the primary coil, the secondary coil and the condenser. The condenser can then be used anywhere. The independent primary is useful for teaching the construction and use of the spark coil. The magnetic interrupter is not needed; by omitting it separable the form of the spark coil becomes cheaper than the usual one.

ADJUSTABLE SUPPORT FOR RECORDING INSTRUMENTS.

For the convenient adjustment of forks and markers so that they may write properly on the revolving drum I have devised the support shown in Figure 10.

The horizontal rod is fastened in any desired position to the upright rod of the drum-carriage by means of the clamp *M* with the screws *A* and *B*. The horizontal rod *T* runs through the hollow rod *P*. At its end is a screw-thread on which the nut *F* is placed. The nut *F* is so adjusted that the hollow rod *P* plays freely but without shake around the horizontal rod. The jamb-screw *E* locks *F* in position. The upper arm *Q*

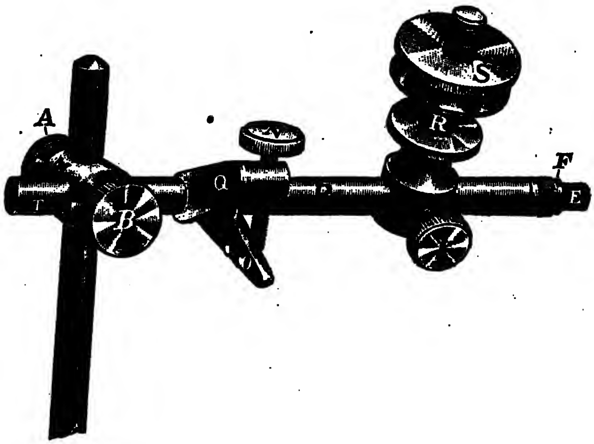


FIG. 10.

with the screw *N* is fast to the horizontal rod, and the arm *O* to the hollow rod *P*. The arm *O* is held against the screw *N* by a spring.

If a fork is to be used, a hole is bored in the wooden base; it is then placed on *R* and screwed tightly down by means of *S*. The fork is then brought into rough adjustment and fastened by *I* on the rod *P*. If a marker is used, it is placed directly on *P*.

The finer adjustment is done by the screw *N* which slowly moves the arm *O* and lowers or raises the fork. Pressure of the finger on *O* lifts the recording point at once from the paper. A view of a fork applied to the drum in this way is to be seen in my New Psychology, Figure 6.

The clamp *M* may be of brass or hard rubber, the latter being necessary when the spark method is used in combination with a marker. (See p. 117 below.)

SYSTEM OF PROJECTION.

Although the requirements of psychology in the matter of projection are in some respects similar to those of other sciences, there are certain important peculiarities that must be borne in mind in providing lanterns, screens, etc. For single, plain slides, the equipment may be the usual one

with an ordinary lantern, and for projection of apparatus the open-work lantern may be used as in physics. Yet these methods leave untouched the subjects of color and binocular vision, which are specifically psychological and which require lantern-work when presented to large classes.

In the following account I shall describe the system which I have developed at Yale.

Triple lantern.—The projection in colors requires a triple lantern of special construction. For stereoscopic projection two of the parts and for plain projection one or two or three parts are used.

The triple lantern which we possess is shown in Figure 11. It is arranged for lime-light, as the color work cannot be done with electric or acetylene light. The three jets are packed closely into one lantern-body. The three condensers are as close together as possible. Three lenses exactly alike are mounted on the front board. The jets have all adjust-

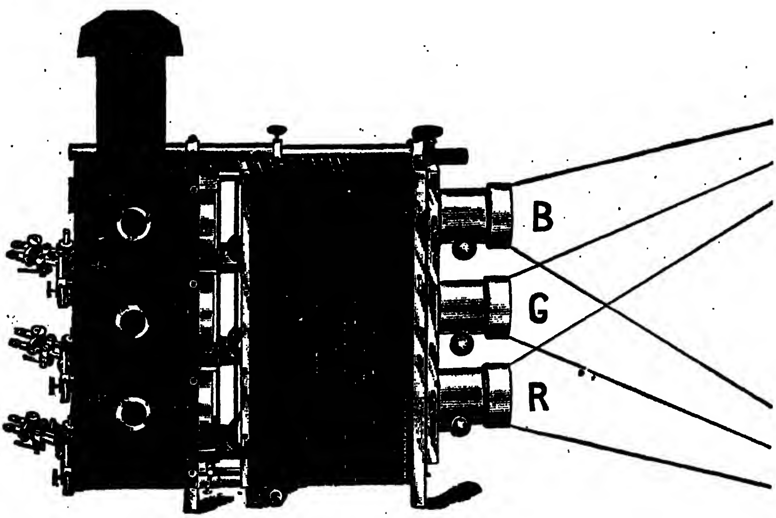


FIG. 11.

ments for regulating the gas, manipulating the lime, etc. Limes turned in the lathe are used in order not to disturb the focus as they are rotated in the lantern. Regulators are placed on the cylinders.

To mount the lantern a shelf of 1½ inch (4 centimeters) pine is built out from the wall and rigidly supported; every precaution is taken to prevent warping. A plate of thick wood or of iron is then prepared just large enough to form a base for the lantern. The lantern is screwed

to this plate. The proper position for the lantern is found; the plate is made perfectly level and is then either screwed to the shelf or is so marked that it can always be brought readily to its proper position. The screen is put in place and the three lenses are brought into perfect registration.

Apparatus lantern.—A regular open-work lantern may be used, but I find it preferable to build one in the following way. A pine board four feet (1¼ meter) long and nine inches (23 centimeters) wide serves as the base. Across it at about one foot (30 centimeters) from the end there is an upright board one foot (30 centimeters) high supported on a narrow base. An opening is made toward the top of this board to admit the condenser-lens. The projecting lens is held by another upright board supported on a base and not attached to the horizontal board. The light, which may be one of the jets from the triple lantern, is held by a rod on a free metal base which is placed at the desired point behind the condenser. One of the condensers of the triple lantern may be readily removed and used in this lantern. The projecting lens may be a very simple one. The large open base and the free adjustment of all the parts make the arrangement of apparatus very easy.

Screens.—Where the room is very high, it is desirable to have the pictures back of the lecture room table. In this case only one screen would be needed; a silvered screen of the appropriate size. When the room is not so high, the silvered screen is placed on rollers just above the front edge of the experiment table; for projections where part of the apparatus is used on the table and part is projected by the lantern another screen is used back of the table. For this latter screen I use muslin sheeting long enough to reach entirely across the room. It is supported by rings on a tightly stretched cord and is readily drawn across or pulled back by other cords. The use of so wide a screen enables me to project two views simultaneously side by side.

The silvered screen is required for stereoscopic work by polarized light; moreover, it is far more brilliant than any white screen.

Single views.—For single views two of the lanterns of the triplet may be used for dissolving. A lantern view is more effective than a chart for various reasons: it is not exposed until it is wanted; it is brilliantly lighted while all else is dark; it must be strictly attended to because it will speedily disappear. Views of apparatus should also be used wherever possible. The actual piece of apparatus is so small that the details are invisible to distant students; a lantern view of the whole or of some essential part greatly aids the understanding. I also find that even the most striking and brilliant instruments rarely command the same attention as a lantern view.

Apparatus views.—For apparatus projection several methods may be followed. Whenever possible, I place as much of the apparatus as I can in full view on the experiment table; the registering part is then placed in the apparatus lantern and projected to one side of the screen behind the table, while the recording point is prolonged so as to write on a smoked glass plate in one part of the triple lantern which projects the record beside the view of the recording apparatus. When this cannot be done, one or two lanterns may be used as desired.

Stereoscopic views.—For stereoscopic projection two methods may be used.

By the color method sheets of red and green gelatine (for lime light) or glass (for electric light) are placed before the condensers of two of the lanterns. Small squares of red and green glass are held before the left and right eyes respectively. The gelatines and the glasses require careful selection. An ordinary white screen may be used.

With the other method two polarizers are placed in front of two of the lanterns with the axes of polarization at right angles.[1] The stereoscopic view-slides are projected simultaneously to the same place. Each student receives an eye-glass consisting of two analyzers with axes of polarization at right angles to each other. The views are thus received by the eyes separately and the result is an object apparently in full solidity. The whole subject of binocular vision lends itself to treatment by this method. Series of stereoscopic slides have been specially prepared for this purpose.

Color views.—For color projection three colored films, red, green, and blue, are placed in the triple lantern. I have devised a slide which shows on the screen the elementary colors singly with their combinations in pairs and in triple. Shades are shown by slowly turning the light down. The various hues and the laws of combination are illustrated by varying the intensities of the jets. The properties of the color triangle and the color pyramid are thus illustrated. When the laws of color are thoroughly impressed by this method, slides of concrete objects are used for study. Thus a group of flowers, Figure 12, affords an illustration of the automatic solution of color equations. The matter is quite complex, but a few illustrations will serve to show how I approach the subject. Every color is the sum of three elements, or $i = x + y + z$. Assume for these elements the three colors red, green, and blue, and let x indicate the number of units of red, y of green, and z of blue. For white we have equal parts of the three elements, or $x = y = z$. The middle stalk of flowers in each slide allows the light to pass fully through it, as can be

[1] A view of these polarizers adjusted to a biunial lantern is shown in SCRIPTURE, New Psychology, Fig. 113, London, 1897.

seen when the views are shown singly. When all three are projected together, it will receive equal illumination from each, and will consequently be white. The stalk on the left in the *R* slide allows the red light to pass, but keeps it entirely back on the *G* and *B* slides, consequently we have $y = o$ and $z = o$ and $i = x$; that is, the stalk appears red in the final picture. In this manner the greens, blues, yellows, purples, etc., with their various hues, tints, and shades may be worked out.

Fig. 12.

"The phenomena of color blindness can also be represented with the tricolor lantern. The usual theory of color blindness, according to which the defect arose by the failure of one of the three fundamental colors, can be illustrated by covering up one of the lenses. For red blindness the red lens is covered, and the resulting picture appears in combinations of green and blue; for green blindness the green lens is covered and for the hypothetical blue blindness the blue one is covered. To illustrate the newer theory, the blue slide is left unchanged, but two slides are made for red and two for green. For the dichromats of the first class—the red-blue persons—the two slides taken through the red ray filter are placed in the red and green lanterns. Thus, in the case of the gladiolus, the slide *R* is thrown on the screen in red light from one lantern, and also in green light from the second lantern, while the *B* slide is thrown in blue as usual. The *G* slide is not used. The result is a picture in combinations of yellow and blue. For the other dichromats—the green-blue persons—the *G* slide is thrown in red light, and again in green light, while the blue remains the same. The *R* slide is not used. The result is also a picture in combinations of yellow and blue, but each particular combination differs from that in the previous

cases. To illustrate monochromasy one lantern alone is used, the color being left to an arbitrary choice."

The method also furnishes a remarkable analogy to the decomposition of the colors by the eye into three fundamentals and their mental recomposition into sensations of color. The tricolor views are taken by a camera used three times in succession with a differently colored screen each time. The red rays impress one of the plates, the green rays the second and the blue rays the third. The three negatives differ in their shading. Three positives are made which differ likewise, as in Figure 12. The three positives produce views appropriately shaded when projected on the screen by the colored lights. The result is a recomposition in natural colors. The approximation to the original colors is close if the slides are properly made and manipulated.

Slide making.

The constant use of lantern views for instruction renders it necessary to provide an equipment for the making of slides at a minimum expense of time. The system which I shall describe was developed expressly for the rapid production of slides for class-room work and of photographs for illustrating books.

The photographic section of the Yale laboratory is located directly under the roof and receives light from a skylight. For work at night the objects to be photographed may be illuminated by burning pieces of magnesium tape. This luminant is used instead of electric light or lime light, because the number of photographs taken at night has been too small to render a regular installation profitable.

For photographing apparatus a table on rollers is provided. White, gray and black backgrounds and table covers are provided to fit on the top of the table. A cover is placed on the table, backgrounds and side-pieces are arranged and the apparatus is placed in the compartment thus formed. The table is then moved until the appropriate lighting is obtained. The choice of white, gray or black for the walls of the compartment is not always an easy matter unless one has had considerable experience with the reflecting qualities of the metals; white is, however, generally used. The strong reflections on polished metal produce sharp streaks of black and white. I find it generally preferable to photograph nickeled or burnished pieces after they have been in use and have slightly lost their polish.

For reproducing drawings, photographs and pictures in books the camera is mounted on a heavy block moving on rails; it may be raised, tipped sidewise or rotated at will. Loose pictures are tacked to a board

at the end of the rails; books are placed on blocks and held open against the board by a rubber band. The adjustment of the camera can be rapidly performed.

When the blocks used to illustrate books are at hand, slides can be printed directly from them.[1] It is best to have the work done by the glass-printer in a clock factory. The metal portion of the cut is mounted on a board of a thickness suited to the particular frame used in the printing. It is inked with a fine ink (e. g., a $2 cut or extra job ink), tempered to the proper consistency with Calcutta boiled oil and Japan drier. The precise degree of temper depends on temperature, humidity, and other conditions. The inking is done by a simple hand roller of the kind used in ordinary printing. The block lies face upward on the table and the piece of plain glass is placed at the appropriate distance on a level with it. A composition roller of glue and molasses, made a trifle harder than the regular printer's roller, is then run forward on two guides. As it passes over the block it takes the impression. On reaching the glass, after one complete revolution, it transfers the ink impression directly to it. I do not think it possible to run this roller evenly enough without the guides; at any rate, it would not pay to waste time in trying it.

The result is a print on the glass just as if on paper. Curiously enough, the prints on the glass are superior to those on paper from the same block. The positives are then finished up as lantern slides in the usual way.

---

[1] SCRIPTURE, *A new method of making lantern slides*, Scientific American, 1895 LXXIII 123.

ELEMENTARY COURSE IN PSYCHOLOGICAL MEASUREMENTS.

BY

E. W. SCRIPTURE.

Owing to the newness of experimental psychology its methods of instruction are still matters which must be determined by trial. SANFORD[1] has developed a course of simple laboratory experiments, but otherwise the problems of systematized laboratory instruction remain unsolved. A very important problem is that of systematic courses in psychological measurements. Among such courses there must be an elementary one. As the results of my experience of five years in trying to develop such a course may be of use, I will illustrate the methods employed by describing some of the exercises.

The aim of this elementary course is similar to that of the elementary courses in chemistry and physics, namely: education and instruction of the general student. It is intended to be part of the regular college education; among elective courses it is specially chosen by students intending to study medicine or to teach. It is a noteworthy fact, however, that the subject matter attracts students who take no other laboratory courses of any kind.

The student makes his own text-book with the aid of: 1. sets of mimeographed instructions which are given out at each exercise; 2. illustrations in the form of prints from blocks, blue-prints, tracings, etc.; 3. references for applications and further reading to some psychological work. The following are copies of some of these mimeograph-sheets with explanatory remarks. The "Preliminary notes" are given out with the first exercise. The first few exercises are of moderate difficulty, but they occupy the inexperienced student for about two hours each. The later exercises are adapted to the increased skill of the student. Since the applications and the bearings of the exercises can be made evident only in a general course on experimental psychology, the laboratory course is taken only in connection with the lecture course. Some idea of the verbal instruction that is given to the pupils and of what they hear and see in the lecture course can be obtained by referring to my New Psychology by means of the topics in the index.

The following exercises are selections from a set of thirty now in use.

[1] SANFORD, Laboratory Course in Experimental Psychology, Boston, 1895.

PRELIMINARY NOTES.

A. Objects of the course.—Practical training in (1) observation, (2) manipulation, (3) computation, (4) deduction, (5) criticism. Elementary acquaintance with (*a*) methods of experimentation, (*b*) methods of measurement, (*c*) construction and use of apparatus, (*d*) special psychological methods. Thorough appreciation of the three fundamental properties of scientific work: (1) accuracy, (2) brevity, (3) neatness.

B. Arrangement of the class.—The class is divided into groups of two persons each. Any student who wishes to do so may select the other member of his own group. One group begins with Ex. I.; another with Ex. II., etc. At the next exercise the group that has had Ex. I. takes Ex. II.; the one that has had Ex. II. takes Ex. III.; etc. At each succeeding exercise a group takes the exercise that follows in numerical order.

C. Instructions to the student.—Look at the index on the bulletin board; opposite the number of the exercise for the day you will find the number of the room in which it has been set up. On the table bearing the number ot your exercise you will find two sets of printed instructions, one for each person. Compare your set with another set marked in red "Corrected Copy," and make any changes that have been indicated in red ink. You will also find all the apparatus of the exercise called for under "Needed." It is set up ready for use. Begin by reading the first paragraph of the instructions and applying it to the apparatus. Take the following paragraphs singly.

After carefully studying the apparatus and its connections take it down and set it up again. In performing the experiments one person serves as experimenter, the other as subject. The places are then exchanged and the experiments are repeated. The subject is to know nothing about the results obtained on himself. The record must be made on the printed blanks.[1] When finished, these records are to be handed to the instructor. They will be marked, the mark being given to the experimenter (who has prepared the record).

The fundamental requirements for the records are accuracy and neatness. See that you understand all the "Points to be noted." If not, consult the instructor. Also see that you can answer the "Questions." It is intended in many cases that you shall get the answers directly from the instructor. The student will be held responsible on all these points. At the end of the exercise place all apparatus in the condition in which it was found. Do not leave until the instructor has inspected and approved your work. When the whole class has finished an exercise, the

[1] A specimen blank will be sent to any one who will ask for it.

final results for each student will be placed in a table and a copy of the table will be handed to the student, together with his record. This "summary" and the original records are to be kept by the student. The examination at the end of the term will include some practical work.

GENERAL INSTRUCTIONS FOR COMPUTATION.

If the method of measuring is sufficiently fine, the results in a set of measurements will differ from each other. The average of these is the most probable value of the quantity. Let the results of a set of n measurements on the same quantity under constant conditions be m_1, m_2, . . . , m_n. The average is

$$m_1 + m_2 + \qquad + m_n$$

It is desirable to have some expression of the uncertainty of the result a, and this is given by the "probable error." The probable error is that error which is as likely as not to be exceeded, or, if r be the probable error of a, it is just as likely that the true value of the quantity lies between $a - r$ and $a + r$ as that it lies outside those limits. Thus, if the average be written $a \pm r$ the probable error r furnishes an index of the uncertainty of a; the smaller the value of r, the greater is the precision of the average a. In works on the theory of errors it is shown that the probable error r is given by the expression

$$r = 0.6745 \sqrt{\frac{v_1^2 + v_2^2 + \ldots + v_n^2}{n(n-1)}},$$

in which v_1, v_2, . . . , v_n are the residuals found by subtracting the individual measures from the average, thus $v_1 = a - m_1$, $v_2 = a - m_2$, . . . , $v_n = a - m_n$.

As an example let there be ten measurements made with equal precision upon a single quantity giving the results $m_1 = 10$, $m_2 = 14$, etc. The computation is as follows:

m	v	v^2
10	1.2	1.44
14	2.8	7.84
16	4.8	23.04
8	3.2	10.24
14	2.8	7.84
6	5.2	27.04
12	0.8	0.64
10	1.2	1.44
12	0.8	0.64
10	1.2	1.44
10)112		9)81.60
$a = 11.2$		10)9.07
		0.91

$\sqrt{0.91} = 0.95$

$\frac{2}{3} \times 0.95 = 0.63$

$a = 11.2 \pm 0.6$

Here the average is 11.2 and its probable error is 0.6; that is, it is as likely that the true value lies between 10.6 and 11.8 as that it is less than 10.6 or greater than 11.8. If the observations had been such as to have given $a = 11.2 \pm 0.9$ the average 11.2 would be much less precise than in the above case.[1]

TABLE OF SQUARES.

1	1	21	441	41	1681	61	3721	81	6561
2	4	22	484	42	1764	62	3844	82	6724
3	9	23	529	43	1849	63	3969	83	6889
4	16	24	576	44	1936	64	4096	84	7056
5	25	25	625	45	2025	65	4225	85	7225
6	36	26	676	46	2116	66	4356	86	7396
7	49	27	729	47	2209	67	4489	87	7569
8	64	28	784	48	2304	68	4624	88	7744
9	81	29	841	49	2401	69	4761	89	7921
10	100	30	900	50	2500	70	4900	90	8100
11	121	31	961	51	2601	71	5041	91	8281
12	144	32	1024	52	2704	72	5184	92	8464
13	169	33	1089	53	2809	73	5329	93	8649
14	196	34	1156	54	2916	74	5476	94	8836
15	225	35	1225	55	3025	75	5625	95	9025
16	256	36	1296	56	3136	76	5776	96	9216
17	289	37	1369	57	3249	77	5929	97	9409
18	324	38	1444	58	3364	78	6084	98	9604
19	361	39	1521	59	3461	79	6241	99	9801
20	400	40	1600	60	3600	80	6400	100	10000

EXERCISE I.—THRESHOLD OF TOUCH.

(Needed: touch-weights, cross-section paper, flexible ruler.)

Apparatus.

The set of touch-weights consists of small cork discs weighing from 2^{mg} upward; they are attached by fine threads to small handles.[2] The weights are marked on the handles.

Experiments.

The subject, with eyes closed, places his left hand, palm upward, on his knee. He is to tell when he feels himself touched. The experimenter gives the warning "Ready" and, about 2 to 5 sec. later, lowers the lightest disc gently till it touches a certain spot on the skin, e. g.,

[1] I am under great obligation to Professor Mansfield Merriman (author of "A Text-book on the Method of Least Squares"), of Lehigh University, for assistance in presenting the methods of computation.

[2] See Fig. 57 of SCRIPTURE, Thinking, Feeling, Doing.

the tip of the index finger; the disc is allowed to rest on the skin for about 1". The experiment is then repeated with the next heavier disc, and then with the other discs in succession. A check is made in the appropriate column of the record blank for each disc as it is felt. The whole experiment is repeated 10 times.

After the whole set of experiments has been made the number of the first disc felt in each experiment is recorded in the column headed m_1, and the number of the disc beyond which all were felt in the column headed m_2. The average is calculated for each set. The former of the two averages may be called the lower threshold, the other the upper one.

Specimen record.

Title of investigation, Threshold of touch.
Experimenter, T. C. McGraw.
Experimented on, W. K. Chisholm.

Apparatus, Touch-weights.
Date, October 5, 1896.
Unit of measurement, milligram.

Weight	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
Exper. No. 1	.	.	.	.	+	+	+	+	+	+	+	+	+	+	+
" " 2	.	.	.	.	.	.	+	+	+	+	+	+	+	+	+
" " 3	.	.	.	.	.	.	.	+	+	+	+	+	+	+	+
" " 4	.	.	.	+	.	+	+	.	+	+	+	+	+	+	+
" " 5	.	.	.	.	.	.	+	+	+	+	+	+	+	+	+
" " 6	.	.	+	+	+	+	+	+	+	+	+	+	+	+	+
" " 7	.	.	.	.	.	+	+	+	.	+	.	+	+	+	+
" " 8	.	.	.	.	+	.	+	+	+	+	+	+	+	+	+
" " 9	.	.	.	.	.	+	+	+	+	+	+	+	+	+	+
" " 10	.	.	.	.	+	+	.	+	+	.	+	+	+	+	+
Times felt	0	0	1	2	4	6	8	9	9	9	9	10	10	10	10

m_1	v_1	v_1^2	m_2	v_2	v_2^2
10	1.2	1.44	10	5.0	25.00
14	2.8	7.84	14	1.0	1.
16	4.8	23.04	16	1.0	1.
8	3.2	10.24	18	3.0	9.
14	2.8	7.84	14	1.0	1.
6	5.2	27.04	6	9.0	81.
12	0.8	0.64	24	9.0	81.
10	1.2	1.44	14	1.0	1.
12	0.8	0.64	12	3.0	9.
10	1.2	1.44	22	7.0	49.
11.2		9)81.60	15.0		9)252.00
		10)9.07			10)28.00
		0.91			2.80

$\sqrt{0.91} = 0.95$

$\frac{2}{3} \times 0.95 = 0.63$

$a_1 = 11.2 \pm 0.6$

$\sqrt{2.80} = 1.67$

$\frac{2}{3} \times 1.67 = 1.11$

$a_2 = 15.0 \pm 1.1$

Theoretical considerations.

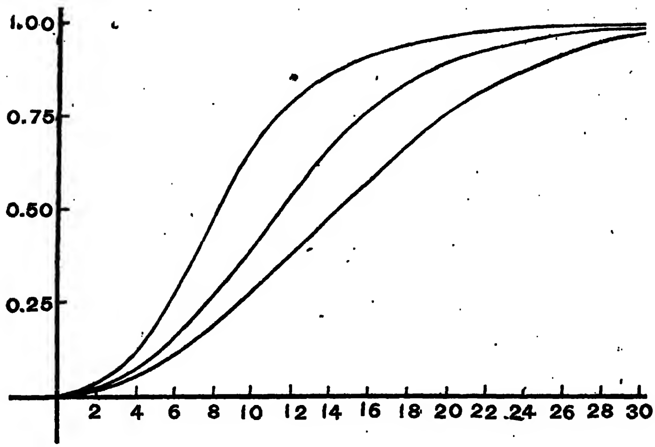


FIG. 13

There is evidently a relation between the weight of the disc and the number of times it is felt. Let the number of times be expressed as a fraction, e. g., a percentage, of the total number of experiments, and suppose the number of experiments to have been very large with the same results. Let this fraction, or percentage, be expressed in the form of a curve, where x denotes the weight of the disc and y denotes the relative frequency with which it was felt. The curve will be one of the forms shown in the accompanying figure. For an extremely sensitive person the curve will be very steep, like that to the left; for persons of less sensitiveness it will be flatter.

The experimenter is to plot the curve for his own record. The plotting is done on cross-section paper; this is paper ruled with horizontal and vertical parallel lines. On one of the horizontal lines lay off the scale of weights 2, 4, etc., with any convenient distance as the unit. On one of the vertical lines lay off a scale of percentages with any convenient distance as the unit. For each weight count upward above its place on the horizontal axis a number of spaces corresponding to its percentage; the ruling of the paper into spaces in groups of 5 and 10 make it possible to do this rapidly. Connect each dot to the following one by a straight line. The fluctuations of this line are due to irregularities in the experimenting and to the smallness of the number of experiments. The true relation of percentage to weight will be more closely indicated by a smooth line, which can either be drawn by the free hand or by adjusting a flexible ruler so as to

pass smoothly among the dots. Owing to the fact that the number of experiments was only 10 instead of an infinite number, the actual curve will differ from the theoretical one; with 100 or 1000 experiments it would approach the theoretical one more closely.

To compare the degrees of sensitiveness of different persons, two quantities can be used: either the disc that corresponds to a certain percentage, say 75%, or the percentage for a certain disc. To use either effectively a large number of experiments would be required; the calculation of the average of the two thresholds as found above gives a sufficiently accurate figure. It is evident that the higher the threshold the lower the sensitiveness; in fact, probably the only proper definition of "sensitiveness" is "the reciprocal of the threshold." "Reciprocal" of a quantity means 1 divided by that quantity. Thus, if two persons have thresholds of a' and a'' respectively, their degrees of sensitiveness will be $1/a'$ and $1/a''$.

Points to be noted.

1. Note that the uncertainty of the threshold is indicated by the size of the probable error. 2. In the curves given in the figure, y is said to be a function of x. This is expressed by $y = f(x)$. The particular curves assumed in the figure are taken from the science of probabilities.

Questions.

1. How would you define "threshold" so as to fit all kinds of sensations? 2. What are presumably some of the mental conditions of the subject that contribute to his probable error?

EXERCISE II.—SKIN SPACE.

(Needed: two æsthesiometers, millimeter scale.)

Apparatus.

In its simplest form the æsthesiometer is a pair of dividers with blunt points. The points are made of hard rubber, in order to eliminate sensations of temperature.

Experiments.

A. Open the æsthesiometer several centimeters. Touch the two points simultaneously to the cheek in a vertical direction; they will be felt as two. Repeat the experiment, reducing the distance between the points each time. To maintain the unprejudiced condition of the subject, insert occasional experiments with only one point touched to the skin. The subject is to state each time whether he feels one point or two. Con-

tinue the experiments till a mistake is made in feeling two points as one. Now apply the æsthesiometer to the scale and record the distance between the points. Repeat the measurement ten times. Find the average and average variation.

B. Repeat the experiments of *A* on the back of the neck in a vertical direction.

C. Adjust one æsthesiometer to 30mm as a standard. Apply it for a moment to the cheek of the subject. Adjust the other æsthesiometer to an arbitrary distance. Apply it likewise to the cheek. The subject is to say whether the second distance was greater or less than double the first. According to the answer adjust the second æsthesiometer differently and repeat the experiment. Proceed as in *A*, the first æsthesiometer being kept at the constant distance of 30mm and the second being gradually changed till a judgment of "equal to double the first" is obtained. Take ten records.

Specimen record.

A			B			C		
m	v	v^2	m	v	v^2	m	v	v^2
23	0.8	0.64	31	4.3	18.49	41	2.6	6.76
21	2.8	7.84	32	3.3	10.89	39	4.6	21.16
25	1.2	1.44	30	5.3	28.09	40	3.6	12.96
23	0.8	0.64	40	4.7	22.09	45	2.4	5.76
26	2.2	4.84	45	9.7	94.09	48	4.4	19.36
21	2.8	7.84	38	2.7	7.29	45	1.4	1.96
27	3.2	10.24	31	4.3	18.49	40	3.6	12.96
26	2.2	4.84	31	4.3	18.49	49	5.4	29.16
23	0.8	0.64	41	5.7	32.49	51	7.4	54.76
23	0.8	0.64	34	1.3	1.69	38	5.6	31.46
23.8		9)39.60	35.3		9)252.10	43.6		9)196.20
		10)4.40			10)28.01			10)21.80
		0.44			2.80			2.18

A	B	C
$\sqrt{0.44} = 0.66$	$\sqrt{2.80} = 1.67$	$\sqrt{2.18} = 1.48$
$\frac{2}{3} \times 0.66 = 0.44$	$\frac{2}{3} \times 16.73 = 1.11$	$\frac{2}{3} \times 1.48 = 0.99$
$a = 23.8 \pm 0.4$	$a = 35.3 \pm 1.1$	$a = 43.6 \pm 1.0$

Points to be noted.

1. Note that the results depend somewhat on the skillfulness of the experimenter. 2. Note that psychologically double does not necessarily correspond to absolutely double.

Questions.

1. What improvements would you suggest in the apparatus and the method of experimenting? 2. How would you express the relation between space on the cheek and space on the neck in your experiments?

EXERCISE III.—ARM-SPACE.

(Needed: arm-space board, cross-section paper.)

Apparatus.

In the arm-space board[1] a wooden scale carries along its upper edge a small glass rod. At the zero point in the middle there is a fixed metal plate. On each side there is a movable slide carrying an adjustable pointer. Before the experiments the pointers are pushed forward as far as possible.

Experiments.

A. The apparatus is placed on a table with the scale away from the subject. The subject, seated with eyes closed or covered, places his forefingers against the zero-plate, one on each side.

B. The experimenter moves up the two slides to the fingers till they press gently. The pointers strike the zero-plate and are pushed back automatically. This eliminates the errors due to the width of the finger, as all readings are to be taken from the end of the pointer.

C. The subject places himself directly in front of the zero-mark and closes his eyes. The experimenter places the left-hand (referring to the subject) slide at a certain distance d_1. The right-hand slide is moved out of the way. The subject moves his left fore-finger evenly outward till it strikes the slide, and then returns it to zero. The experimenter quietly moves the slide out of the way, and the subject then moves his finger again till it seems to be in the same place as before. The experimenter now moves the slide up till it touches the finger and reads the record at the end of the pointer. The tenths of a centimeter are estimated by the eye. The result in millimeters is placed in the column m_1 of the record blank.

Some other distance d_2 is now chosen and the experiment is repeated, giving a result m_2. Likewise d_3, d_4 and d_5 are used. The five distances are chosen as follows: 100, 200, 300, 400, 500 millimeters. The experiments are performed in this order: from d_1 to d_5, from d_5 to d_1, from d_5 to d_1, from d_1 to d_5. Eight complete sets are made, giving eight records for each distance. Find the averages and probable errors. Denote the averages by $a_1, a_2, \ldots, a_5$. The difference between the given distance and the average result for that distance is the constant error of the estimate. There are thus five constant errors, $c_1 = a_1 - d_1$, $c_2 = a_2 - d_2$, . . . , $c_5 = a_5 - d_5$. The constant error expresses the average inaccuracy in reproducing the given distance. The probable error expresses the irregularity. Both these quantities depend on the values of d.

[1] New Psychology, Fig. 44.

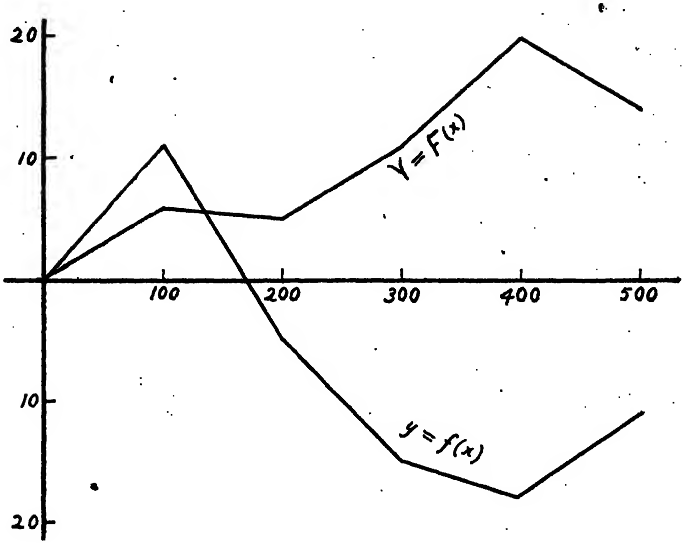


FIG. 14.

To make plain the laws of dependence, the results are to be expressed in two curves $y = f(x)$ and $Y = F(x)$ where $x = d_1, d_2, \ldots, d_5$ and y and Y are the constant errors and the probable errors. To draw these curves a certain distance is selected on the cross-section paper to represent d_1, and the points $d_1, d_2, \ldots, d_5$ are laid off on the horizontal axis. Any convenient distance is chosen for $y = 1$ and the ordinates for $y_1, y_2, \ldots$ are erected. On joining the tops of these ordinates by a line the curve of results is indicated. The relation of $Y_1, Y_2, \ldots, Y_5$ to $d_1, d_2, \ldots, d_5$ is indicated in a similar manner.

Specimen record.[1]

$d_1 = 100$		$d_2 = 200$		$d_3 = 300$		$d_4 = 400$		$d_5 = 500$	
m_1	v_1^2	m_2	v_2^2	m_3	v_3^2	m_4	v_4^2	m_5	v_5^2
105	79.21	193	6.25	267	334.89	355	723.61	454	1253.16
116	26.01	197	2.25	281	18.49	381	0.81	494	21.16
110	0.81	189	42.25	297	136.89	399	292.41	473	268.96
107	15.21	201	30.25	285	0.09	398	259.21	505	243.36
108	8.41	195	0.25	280	28.09	371	118.81	487	5.76
115	16.81	195	0.25	269	265.69	393	123.21	500	112.36
114	9.61	196	0.25	305	388.09	408	681.21	507	309.76
112	1.21	197	2.25	298	161.29	350	1017.61	495	31.36
8)887	7)157.28	8)1564	7)84.00	8)2282	7)1333.52	8)3055	7)3216.88	8)3915	7)2245.88
110.9	8)22.47	195.5	8)12.00	285.3	8)190.39	381.0	8)459.55	489.4	8)320.84
	2.81		1.50		23.79		57.44		40.11

[1] The student need not record the residuals v but should at once write the squares, v^2.

$\sqrt{2.81} = 1.68$
$\frac{2}{3} \times 1.68 = 1.12$
$a_1 = 110.9 \pm 1.1$
$c_1 = +10.9$
$r_1 = 1.1$

$\sqrt{1.50} = 1.22$
$\frac{2}{3} \times 1.22 = 0.81$
$a_2 = 195.5 \pm 0.8$
$c_2 = -4.5$
$r_2 = 0.8$

$\sqrt{23.79} = 4.88$
$\frac{2}{3} \times 4.88 = 3.25$
$a_3 = 285.3 \pm 3.3$
$c_3 = -14.7$
$r_3 = 3.3$

$\sqrt{57.44} = 7.58$
$\frac{2}{3} \times 7.58 = 5.05$
$a_4 = 381.9 \pm 5.1$
$c_4 = -18.1$
$r_4 = 5.1$

$\sqrt{40.11} = 6.33$
$\frac{2}{3} \times 6.33 = 4.22$
$a_5 = 489.4 \pm 4.2$
$c_5 = -10.6$
$r_5 = 4.2$

$c = f(d)$		$r = F(d)$	
For $d = 100$,	$c = +11$	For $d = 100$,	$r = 1.1$
$d = 200$,	$c = -7$	$d = 200$,	$r = 0.8$
$d = 300$,	$c = -15$	$d = 300$,	$r = 3.3$
$d = 400$,	$c = -18$	$d = 400$,	$r = 5.1$
$d = 500$,	$c = -11$	$d = 500$,	$r = 4.2$

Points to be noted.

1. The method of getting tenths by the eye is in this case convenient and accurate. 2. Automatic elimination of a constant error (width of the finger) from the readings. 3. Equalizing the influences of fatigue, practice and other progressive errors by changing systematically the order of the experiments.

Questions.

1. If the probable errors were directly proportional to the values of *d*, what form would the curve take? 2. What would a recorded constant error or a probable error of 0 mean?

Exercise IV.—Memory.

(Needed: two sets of geometric figures, two bands of syllables, two bands of colors, revolving cylinder, screen and metronome.)

Apparatus.

The metronome is a convenient pendulum arrangement for marking off intervals of time when great accuracy is not required. The clock-work is wound by the screw at the side; the cover is removed from the front; the pendulum is released and the weight is set at sixty. When started, the metronome will mark off seconds.

The two cards for the experiments with figures are in separate envelopes, one for each subject. The experimenter takes the envelope containing the card which he is to use on the other person as subject. The subject must not see beforehand the card that is to be used on him.

The revolving cylinder is moved by clockwork, which is kept wound by the appropriate key. It is started by releasing the brake. It revolves once in 10 seconds.[1]

One band of syllables and one band of colors will be found in each envelope with the card mentioned above.

A screen is placed before the cylinder so that only one syllable or color is seen at a time.

Experiments.

A. A pad of blank paper is placed before the subject. The experimenter holds the card with figures and at a beat of the metronome he shows it to the subject, counting 0, 1, . . . , 10 and turning down the card at 10. The subject immediately tries to reproduce on the blank paper all the figures he saw. The paper is numbered and handed to the experimenter. The card is again shown for 10 seconds and the subject again tries to reproduce the figures. This is repeated until all are reproduced correctly, unless success is not reached before the 15th trial, at which point fatigue generally begins. A record is made of how many were reproduced correctly in shape and arrangement on each trial.

B. The band of syllables is slipped on the cylinder. When it is set going it exposes one syllable per second through the screen. During the first revolution the subject calls off each syllable as he sees it; thereafter he tries to call off each syllable just before it appears, correcting himself if wrong. The experimenter notes the number of revolutions performed by the drum. This is continued until all are called off directly or until the 20th revolution. The number of revolutions is recorded.

C. The band of syllables is replaced by the band of colors and the experiment is repeated. The subject notes and recalls the colors as much as possible by visual memory and does not attempt to name them.

Points to be noted.

1. Difficulty of remembering without making external associations.
2. The prominence of motor and auditory elements in *B* and *C*.

Questions.

1. What would be some of the problems of memory that might be answered by the experiments with syllables? 2. What sources of inaccuracy do you notice in the methods of experimenting?

[1] In case the kymograph is used, it is properly adjusted by the instructor beforehand. The study of the kymograph, which is too difficult for the student at this point, is brought forward in Exercise VIII.

EXERCISE V.—ILLUSION OF LENGTH.

(Needed: illusion board, millimeter measure.)

Apparatus.

The illusion board is made as follows. A strip of celluloid is tacked at the corners to a board 1 foot × 9 inches ($30^{cm} \times 23^{cm}$) large. The opening *ABCD* is cut in it. Six celluloid strips are prepared, such that they can be slipped under the left-hand edge of larger sheet and appear in the opening with one edge crossing at the middle *PQ*. Six some-

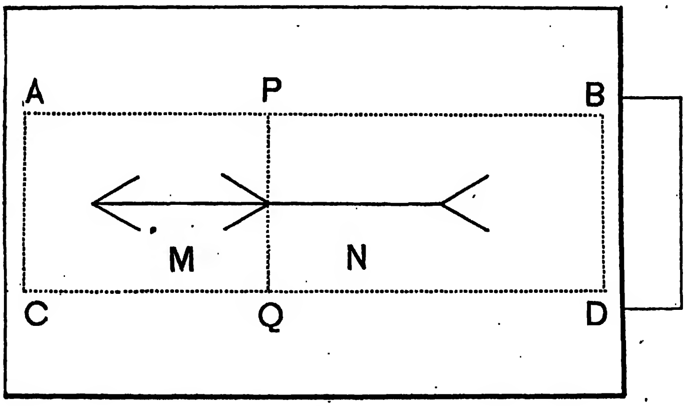


FIG. 15.

what longer slips are prepared, such that they can be slipped under the right-hand edge and extended past the middle under the shorter slips. The shorter slips bear diagrams of the kind shown to the left in Figure 16; the longer ones bear diagrams of the kind shown to the right. Six pairs of slips are used with diagrams of the forms indicated in the following list; the slant lines are called "angle lines."

Mark on the card	*a*	*b*	*c*	*d*	*e*	*f*
Length of angle-line, in millimeters	30	30	30	15	30	60
Angle between angle-line and horizontal	15°	30°	60°	30°	30°	30°

The length of the constant horizontal line is not to be measured until all experiments are completed.

Experiments.

A. The slips marked *a* are inserted in the manner described. The subject holds the board directly in front perpendicularly to the line of vision at the ordinary reading distance. He moves the longer slip until the two parts of the horizontal line appear equal. He then hands the

board to the experimenter, who measures N, records the result, pulls the longer slip out slightly and hands the board back.

A_l. The experiment is repeated with N on the left-hand side.

B_r. The slips marked b are used as in A_r.

B_l. As in B_r with N to the left.

C_r. Slips c; N to right.

C_l. " c; " " left.

D_r. " d; " " right.

D_l. " d; " " left.

E_r. " e; " " right.

E_l. " e; " " left.

F_r. " f; " " right.

F_l. " f; " " left.

Each record is made in a separate column on the blanks. The experiments are performed four times in the following order: 1. A_r to F_l (as in the list above); 2. F_l to A_r; 3. F_l to A_r; 4. A_r to F_l.

Computation.

1. Find the average for each column, writing the results in whole numbers.

2. Find the averages for A, B, etc., thus:

$$A = \frac{A_r - A_l}{2},\ B = \frac{B_r - B_l}{2},\ \text{etc.}^1$$

3. Measure M.

4. Find $I_A = A - M$, $I_B = B - M$, etc. Do not disregard the sign. The results I_A, I_B, I_C give the amount of the illusion as a function of the angle, or $I = f(R)$. The results I_D, I_E, I_F give the amount of the illusion as a function of the length of the end lines, $I = F(S)$.

Points to be noted.

1. Notice carefully the system on which the experiments are arranged, in order to equalize the effects of progressive errors. 2. Notice that an orderly arrangement of the slips on the table and an appropriate routine in performing the experiments are conducive to the saving of time.

---

[1] Results for 13 students in 1896 were as follows:

Subject.	A	B	C	D	F	G	H	I	J	O	P	Q	S
A	90	95	83	84	71	81	84	81	81	92	90	88	82
B	97	99	83	84	75	83	86	86	85	93	93	88	86
C	97	100	90	85	79	87	90	92	88	96	92	90	83
D	96	100	84	88	78	86	90	87	85	96	95	92	85
E	96	98	79	80	75	85	87	82	83	92	92	86	80
F	97	96	80	82	69	84	86	82	84	92	92	89	80

Questions.

1. What are "progressive errors?" Mention some. 2. Why not omit the experiments under E_r and E_l and substitute in $I=f(S)$ the values from B_r and B_l? 3. How would you compute the results in order to determine the difference in the illusion between N to the right and N to the left?

EXERCISE VI.—THRESHOLD OF INTENSITY FOR SOUND.

(Needed: differential audiometer, telephone, battery of 1 A, i. e., of 1 ampére.)

Apparatus.[1]

The audiometer comprises two primary coils at the ends of a base and a movable secondary coil in the middle. The wires from the battery are brought to the binding posts at one end of the apparatus. The current passes around the one primary coil clockwise and then around the other counter-clockwise. When this current is broken by the key at the other end of the apparatus, a momentary current is aroused by each primary coil in the secondary coil.

The telephone is connected with the secondary coil. Place the secondary coil close to one of the primaries; hold the telephone to the ear and, gently moving the key, note that the induced current produces a sound. Repeat with the secondary close to the other primary.

Since the primaries are wound in opposite directions the induced currents must be in opposite directions. Consequently the sound diminishes from its maximum loudness at either end to zero at the middle.

Experiments.

A. The secondary coil is placed sufficiently near the primary to give a distinctly audible sound. The subject holds the telephone to the right ear and closes the left with the finger. He sits with his back to the apparatus.

The experimenter repeatedly interrupts the current by slightly moving the key. The subjects responds whenever he hears the click in the telephone. The secondary coil is slowly moved toward the middle until the subject first loses the sound. The sound can be regained frequently after it has been lost, but this is disregarded. The graduation is in millimeters.

B. The secondary coil is started at the middle and moved till the subject first hears the sound.

The left ear is tested in like manner.

[1] A brief description of the simplest form of the lamp battery (see p. 77) is given at this point; the extra-circuit battery appears in Ex. XV.

Computation.

Find the averages for A and B for a set of four experiments alternated so as to equalize progressive errors.

Find the general average; denote it by t.

These values represent the faintest perceptible sound, or the threshold, under the particular conditions of the experiment.[1]

If the average value for normal individuals is T, then the subject's relative deafness can be stated as $d = \frac{t}{T}$ or his sharpness of hearing as $h = \frac{1}{d} = \frac{T}{t}$. With this particular apparatus and 1 ampère of current, $T = 200^{\text{mm}}$.

Points to be noted.

1. The scale is a purely arbitrary one. 2. The sound is very little influenced by any changes in the current.

Questions.

1. How would you define "sensitiveness to sound?" (See Ex. I). 2. What sources of error are possibly present?

Exercise VII.—Dynamometry of voluntary action.

(Needed: finger dynamometer, piston recorder, rubber tube, air valve, simple recording drum, smoking and varnishing arrangements, screw-vise.)

Apparatus.

a. The dynamometer.[2] This consists essentially of two spring-steel rods, rigidly fastened in a base block. These rods can be deflected inward by pressure on two small knobs. The extent of the deflection is indicated on a scale at the ends. This scale has been graduated by actual trial; the unit is the kilogram.

[1] The following results were obtained from 16 students in 1896; the unit is the centimeter.

Subject.		A	B	D	E	F	H	I	J	K	L	M	O	P	Q	R	S	Average.
Right	A	22	17	21	17	25	27	17	18	26	16	44	26	12	12	11	13	20
	B	19	27	27	23	25	29	19	23	25	18	36	27	14	11	19	15	22
Left	A	20	17	22	18	23	22	28	19	25	17	25	17	11	11	19	14	19
	B	20	19	26	20	25	22	26	28	24	15	25	19	12	11	20	16	21

[2] See New Psychology, Figs. 4 and 24.

A glass cylinder is attached to one of the rods of the dynamometer and a rubber piston is connected with the other rod by an aluminum bar. As the rods are pressed together the air of the cylinder is forced out through a rubber tube attached to the bottom. This cylinder is called the receiving cylinder.

b. Piston recorder. At the other end of the tube is the recording cylinder, constructed similarly to the receiver. The piston of the recording cylinder is connected to an aluminum lever which is lengthened by a very light straw rod ending in a fine quill point. As the air, driven out from the receiver, is forced into the recorder, the quill point must repeat on a highly enlarged scale the movement of the rods of the dynamometer. There are various adjustments on the recorder for changing the amplification, for placing the point higher or lower, for making the plane of movement tangential to the surface of the drum, for adjusting the cylinder, etc.

Each piston is rendered air-tight by a drop of oil. The valve in the rubber tube serves to let air out or in when it is desired to change the position of the recording point.

c. Recording drum. This is a carefully turned brass cylinder, revolving on an axis. The drum is first placed with its axis horizontal. The end of a sheet of glazed paper is moistened with paste. It is then stretched tightly and smoothly around the drum and the pasted end is lapped over the other one. This makes a tight band of paper around the drum; no paste should be allowed to get on the drum itself. A gas flame is held beneath the drum so that it deposits soot on the paper; the drum is slowly turned in order to keep the paper from burning.

d. Adjusting the apparatus. The drum is placed so that its axis is vertical. The quill point of the recorder is brought near the smoked surface by moving the support and by adjusting the screws that hold it. Then the point is brought into light contact with the surface by turning the adjusting screw at the side. The lever should be as nearly as possible at a tangent to the surface of the drum. As the drum is turned, a line is drawn in the smoke by the quill point.

The dynamometer is held between the tips of the thumb and index finger; the base block rests lightly in the palm of the hand. A comfortable position is found and the eyes are closed.

Experiments.

A. Scale of effort. At the word "One" from the experimenter the subject presses the dynamometer lightly. At the word "Two" he presses it twice as hard as before; at "Three" three times as hard and at "Four" four times as hard.

When this has been done a number of times in order to familiarize the subject with the experiment, the experimenter gives the drum a slight turn before each pressure so that the records are separated distinctly. Five sets of four marks each are thus obtained.

The dynamometer is placed in a screw vise so that the cheeks of the vise take the places of the fingers of the subject. The drum is turned so that the quill point is at the first record. The vise is screwed up till the point has moved as far as the original record; the number of kilograms corresponding to this movement is read off from the scale. The tenths of a kilogram are estimated by the eye. The result is recorded in the first column of the record blank. The drum is now turned till the point is opposite the second record; the vise is screwed up and its value determined as before. The result is placed in the second column. In the same manner all the records are determined, the results being placed in the columns 1, 2, 3, 4 according to the original intention of the subject in exerting the pressures.

In each set of records the pressures were intended to stand in the relation of 1, 2, 3 and 4; the actual relations are found by dividing each record of a set by the record for the first pressure in that set. Thus the records 1.1, 1.8, 2.4, 3.2 stand in the relations of 1.0, 1.6, 2.2, 2.9. This is done separately for each set. The results for each pressure are averaged. The following is a specimen record.

Mental scale of pressure	I	II	III	IV
Actual pressure exerted	1.1	1.8	2.4	3.2
	1.8	2.1	2.8	3.7
	1.3	1.9	2.5	3.3
	1.0	1.8	2.4	3.1
	1.3	1.7	2.5	3.5
Relative pressure exerted	1.0	1.6	2.2	2.9
	1.0	1.2	1.6	2.1
	1.0	1.5	1.7	2.5
	1.0	1.8	2.4	3.1
	1.0	1.3	1.9	2.7
Average	1.0	1.5	2.0	2.7

The experiments are repeated, beginning with a very strong pressure and proceeding in the the order "Four," "Three," "Two," "One."

B. Curve of fatigue. The preparations are made as before. At the word "Go" the subject presses on the dynamometer as strongly as possible and maintains the pressure at its maximum until told to stop. The experimenter keeps the drum turning slowly for 10 sec. by the watch; thereupon he calls "Stop." The line traced upon the drum shows the

fluctuation in the maximum amount of effort. The fatigue curve is found by drawing a horizontal line from the highest point at the beginning of the record and then turning the record bottom up; the curve then runs, of course, from right to left. The amount of fatigue is to be found by taking readings at the beginning and at the end of the curve in the manner described under *A*.

C. Diversion of energy. The preparations are made as before, but instead of closing the eyes the subject keeps them fixed on a printed page. At the word "Go" he is to press as hard as possible; this maximum pressure is to be kept up without any relaxation till the end of the experiment. Shortly after starting the experimenter calls "Read" and at the same time makes a check on the drum near the quill point by means of a small stick or a pencil. The subject begins reading aloud at the signal and, without relaxing the pressure, continues to read until the words "Stop reading."[1]

D. Preserving the record. The drum is placed horizontally, the paper is slit across, one end is caught by a clamp, the sheet is run through a solution of shellac and is hung up to dry.

This shellac solution is contained in a large bottle at the varnishing stand. Lift the bottle from the lower shelf and place it on the upper one. The varnish runs through the rubber tube and floods the varnishing tray. The shellac solution is composed of 1 part by volume of saturated solution of shellac in alcohol and 4 parts of 95% alcohol. In running the sheet through the solution get the fore edge of the sheet under the solution first and keep the smoked side upward. After the sheet has been varnished, the bottle must be replaced on the lower shelf; the varnish runs back into it and is kept from evaporation.

Points to be noted.

1. Possibility of establishing mental scales. 2. The falling off in the effort in what is meant by "fatigue" in this case. To call it "the effect of fatigue" would bring in assumptions not justified by the experiment; a scientific definition must start with the facts as immediately given.

Questions.

1. How was the standard physical scale established? 2. What general conclusions would you draw concerning mental energy? 3. How many adjustments can you point out on the piston-recorder?

[1] Such a record is shown in Fig. 48 of The New Psychology.

Exercise VIII.—Rhythmic movements.

(Needed: **Jacquet graphic chronometer, kymograph, Marey tambours, upright wooden scale, paper, smoking and varnishing arrangements, 2 standards.**)

Apparatus.

a. Graphic chronometer. This is essentially a fine stop watch with a recording point and electric contact. The smaller dial indicates seconds, the larger one minutes. The chronometer is wound by the screw at the back; it will run for 4^h without error due to laxity of spring, or 6^h with a small error. The catch *b* at the bottom, when moved to the right, starts the chronometer; when to the left, stops it. Pressure on the catch *a* at the side returns the hands to 0. The recording point *d* makes a movement once a second, or five times a second, according as the catch *c* at the back is pushed in or pulled out. The extent of the movement of the recording point is regulated by the screw *e* beneath it. When the chronometer is placed vertically the weight of the recording lever is sufficient to bring it back when moved, but when it is in a horizontal position the screw *f* at the right-hand side should be made to bear lightly on the spring at the opposite end of the lever. The chronometer is held on the support by the screw *l*. When used with the drum, it is brought near the surface at a tangent by moving the support; the finer adjustment is then made by turning the screw *m* in front.

b. Kymograph. This is a recording drum moved by clockwork. It differs from the hand-drum by having its speed so carefully regulated that, when its rate of revolution is once determined, it can be depended upon to maintain that rate with a high degree of accuracy, provided the spring is kept wound up to about the same tension and the whole apparatus is in perfect order. The lettering used in the following instructions will be found painted on the apparatus at the appropriate points.

First place the drum in the separate horizontal support as in Ex. VII. Place some paste on one end of the sheet of glazed drum-paper. Stretch the paper around the drum tightly and bring the pasted end over the other end. Coat the paper with smoke by holding a gas flame close beneath it.

Lift the drum from the support, grasping it around the ring *O* at the end. Raise the spring *G* of the kymograph by the arm *F* till it catches. Let the end of the drum-axle drop into the socket *P*. Bring the groove of the ring *O* up till it catches on the wheel at the end of the arm *N*. Bring the top of the axle just below the socket held by *G*, and let *F* snap. The drum is now in position; it should be turned till the projecting point at the bottom of the axle catches in a notch of the spring *P*. If the kymograph is not firm upon the table, adjust the leg *M*.

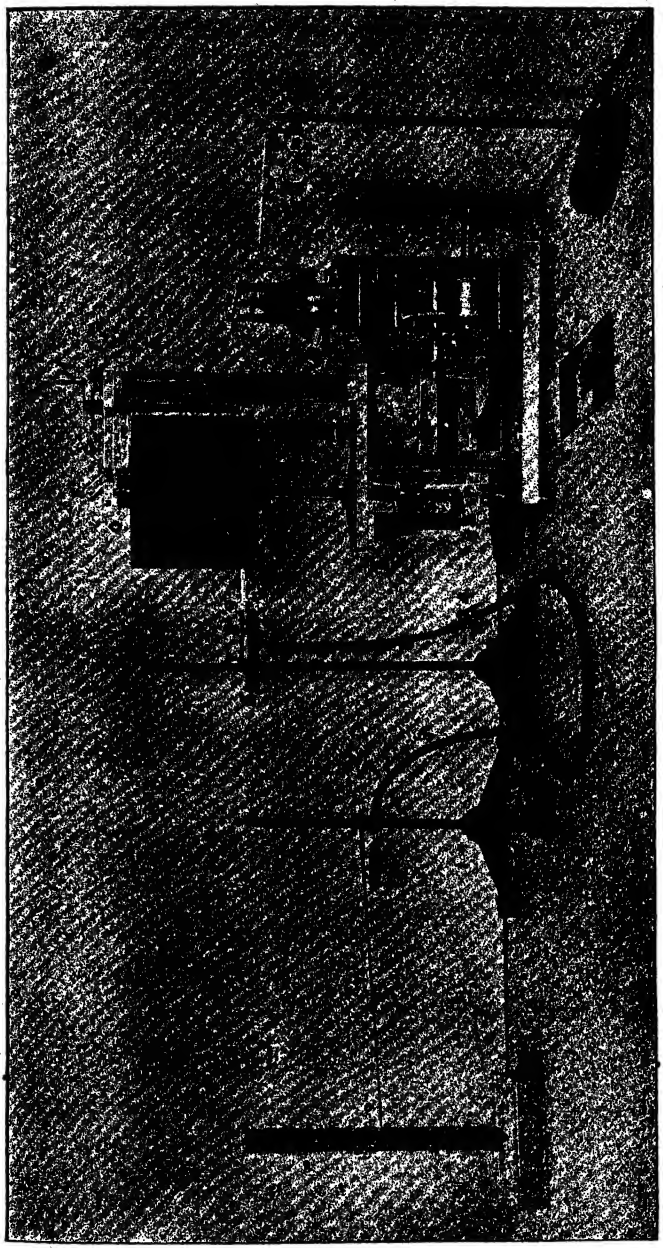


Fig. 16.

Wind up the clock-spring by the handle *A*. Move the brake *E* in order to release the governor *D*. When the screw *B* is tight the drum will turn with the clockwork; when it is loose, the drum is disconnected. The connection of the clockwork with the drum axle is established by the large friction disc which presses against the small friction roll *X*. When handling the drum, always disconnect it by turning *B*; this keeps the friction disc from being ground by chance movements of the roll *X*.

The speed of the friction disc is changed by different combinations of the gears of the clockwork. The case of the clockwork can be opened by turning two projecting screws at the side. There are two gears that move sidewise on their axles, a lower one (white stripe), and an upper one (red stripe). The following table gives the speeds approximately obtainable by the different combinations.

SPEED NAME.	POSITION OF LOWER WHEEL.	POSITION OF UPPER WHEEL.	FRICTION ROLL AT LOWEST POINT.	FRICTION ROLL AT HIGHEST POINT.
I	Left.	Right (weak spring).	$1^h\ 30^m$	12^m
II	Left.	Left (medium spring).	6^m	45^s
III	Left.	Middle (strong spring).	2^m	15^s
IV	Right.	Right (weak spring).	12^m	$1\frac{1}{2}^m$
V	Right.	Left (medium spring).	40^s	5^s
VI	Right.	Middle (strong spring).	16^s	2^s

There are three sets of springs for the governor; that set should be chosen which allows the wings of the governor to take a middle position when in motion. When the upper wheel is in the middle position the screw *C* should be turned so as to bring the little wheel at the end of the arm into position between the largest and smallest cog-wheels.

The intermediate speeds between the figures in the table are obtained by moving the roll *X* by means of the screw *R*. An index connected with *X* moves over a scale so that a speed once found can be reproduced by direct adjustment of the index to the same point; to avoid back-lash the adjustment should be made in the direction from zero upward. Adjust the kymograph for this exercise to about 20^s for 1 revolution.

c. Tambours. The essential principle of the tambour is found in its construction as a metallic air-chamber with a rubber top and a side tube. There are two tambours, the receiver and the recorder.

Any desired movement may be communicated to the straight lever (1) of the receiver (2). This lever communicates the movement to the air inside by its varying pressure on the rubber top. The movement of the air is communicated along the rubber tube (3) to the recorder (5). The

rubber top of the recorder moves in response to the movements of the air, and the light curved lever (9) resting on it consequently repeats the movements of the straight lever of the receiver. The point of connection (8) to the recording lever can be moved so as to obtain different degrees of amplification; the body of the tambour is kept centered beneath the point of connection by a screw (6) at the back. For the present exercise any convenient amplification is used. The position of the point on the drum is adjusted by the arm (7) which moves the fulcrum. The valve (4) is used as in Ex. VII.

Experiments.

A. Getting the time-line. The drum is set in motion. The graphic chronometer, adjusted to beat seconds, is placed on the upright support. The support is moved till the recording point nearly touches the smoked surface at a tangent. The point is brought into light contact by the adjusting screw. The chronometer thus traces a line with checks at intervals of 1^s. The chronometer is then carefully removed and placed in its box.

B. Recording an instinctively chosen rhythm. The recording tambour is placed so that its point draws a line on the drum. The receiver is arranged with its lever in front of a vertical scale.

The subject takes the straight lever between thumb and finger at the point marked in black. He is to move it up and down as regularly as possible over a distance of about 3^{cm}. By "regularly" is meant evenly and at regular intervals. While this is being done, the experimenter allows the drum to make one revolution. By turning the handle *H*, the drum is then lowered sufficiently for another record.

C. Recording an arbitrary rhythm. The subject tries to beat twice as fast as before.

Computation.

The drum is lifted out of the apparatus by grasping it around the ring and raising the lever *G*. It is placed in the horizontal support. The experimenter writes on it with a pointed instrument the name of the subject, the date and the time. With the point of a knife the paper is slit across, the thumb being kept over the beginning of the slit in order to keep the paper from falling. The end of the paper is caught by a varnishing clamp. The paper is run through the varnishing solution of shellac and hung up to dry.[1]

[1] Observations connected with this experiment led me to report (*Science*, 1896, n. s. IV 535), the following law, subject to amplification and correction by further experiment. The probable error (all apparatus errors being negligible) is a good measure of

When the paper is dry the lower edge containing the time-record is cut off to serve as a scale of seconds. Ten of the distances from top to top of the waves in each rhythm are measured by this scale, giving the results in seconds and estimated tenths. The average and the character-variations are found in each case.

Specimen record.

Natural rhythm.			Arbitrary rhythm.		
m	v	v^2	m	v	v^2
1.8	0.16	0.0256	1.1	0.05	0.0025
1.8	.16	.0256	0.9	.15	.0225
1.7	.06	.0036	1.0	.05	.0025
1.5	.14	.0196	1.2	.15	.0225
1.7	.06	.0036	0.8	.25	.0625
1.5	.14	.0196	1.0	.05	.0025
1.6	.04	.0016	1.1	.05	.0025
1.8	.16	.0256	1.6	.55	.3025
1.4	.24	.0576	0.9	.15	.0225
1.6	.04	.0016	0.9	.15	.0225
1.64		9)0.1840	1.05		9)0.4650
		10)0.0204			10)0.0519
		0.0020			0.0052

$\sqrt{0.0020} = 0.04$
$\frac{2}{3}\times 0.04 = 0.03$
$a = 1.64 \pm 0.03$

$\sqrt{0.0052} = 0.07$
$\frac{2}{3}\times 0.07 = 0.05$
$a = 1.05 \pm 0.05$

Points to be noted.

1. The method of obtaining 10ths of a unit by the eye is in this case just as accurate as if a carefully prepared scale were used. 2. Although

the subject's irregularity (see above p. 21, note 1), or of the difficulty of his mental processes. Using it thus as a measure of the disadvantage of a rhythm we can express the relation of the disadvantage to the length as $r = f(t)$ where r is the probable error and t the length of the time in the rhythmic movement. The law proposed is

$$\frac{r}{|t - T|} = \text{constant},$$

where r and t have the same meanings as before, T is the length of the time chosen naturally and $|t - T|$ indicates that the sign of the quantity is disregarded. In other words, the amount of irregularity is proportional to the deviation from the natural rhythm. The relation here observed is illustrated by the well-known fact that in such rhythmic movements as walking, running, etc., a certain frequency in the repetition of the movement is most favorable to the accomplishment of work. Thus, to go the greatest distance in steady traveling day by day, the horse or the bicyclist must move his limbs with a certain frequency: not too rapid, as this would fatigue and cut short the journey, and not too slow, as this also would be fatiguing and wasteful. This favorable frequency is a particular one for each individual and for each condition in which he is found; any deviation diminishes the final result.

the records could easily be read in 100ths, the degree of accuracy appropriate to the experiment lies in 10ths.

Questions.

1. What is the relation between the probable error and regularity?
2. How would you express this relation mathematically?

EXERCISE IX.—MAXIMUM RAPIDITY OF REPEATED VOLITIONS.

(Needed: recording drum, paper, smoking and varnishing arrangements, 100 v. d. electric fork, fork support, double contact key, spark coil, condenser, battery of 1A, battery of 4A.)

Apparatus.

a. Recording drum. This drum[1] consists essentially of an evenly turned cylinder rotating on two centers. Parallel to the axis of the drum are two rails guiding an upright support, called the marker support. The support is moved by a screw operated by a handle at the end. Glazed drum-paper is stretched around the drum and smoked in the manner described in Ex. VII.

b. Electric fork. An electric current of 1 ampère is brought to the binding post at the back of the fork. It travels along the prong to the platinum wire. When this wire is in contact with the plantinum-covered disc the current passes to the base of the magnet, whence it goes through the wire of the magnet, out at the insulated post and back to the battery. While the current is passing, the coil becomes magnetic and pulls the prongs of the fork inward. If the platinum wire is in very light contact with the disc, this movement of the prongs will separate them, and the current will be interrupted. Consequently the coil ceases to be magnetic and the prongs fly outward. The outward movement, however, brings the platinum wire into contact with the disc again; the current passes through the coil, and the movement begins as before. With a proper adjustment of the disc in relation to the platinum wire the fork will continue to vibrate as long as the current is supplied. The proper adjustment is attained by starting the disc away from the wire and screwing it up till it just touches—which can be seen from the darkening of the little lamp of the battery—and then giving about ⅛ of a turn more. If the fork does not begin to vibrate of its own accord, it is

[1] See Fig. 33 in Stud. Yale Psych. Lab., 1893 I 100, and Fig. 6 in The New Psychology.

started by a light blow of the finger. A light recording point of fine spring steel is attached to one prong.[1]

c. Fork support.[2] The object of the fork support is to provide a delicate and convenient adjustment of the contact point on the smoked paper. It is fastened to the marker support of the drum by the clamp *M*, by which it can be raised, lowered or turned as desired. The rod *R* is placed in the hole through the base of the fork; the screw *S* clamps the base firmly. The screw *I* gives adjustment on the rod *P*. The fork is first placed nearly in position with its steel recording point at a tangent to the drum and its plane of vibration parallel to the drum axis. It is now lowered by the screw *N*, acting on the arm *O*, till the point is in good contact with the paper.

d. Double contact key.[3] This key consists of a lever moving on a bar hung between centers. A spring holds the front end of the key up; the tension of this spring is adjusted by the screw *Z*. It should be great enough to hold the lever up as far as it will go, but small enough to offer the least possible resistance to movement. At *Y* a platinum point is inserted. Just below *Y* there is another point *X*, which is supported by a ring of hard rubber so that there is no metallic connection with the frame. A wire leads from *X* to the binding-post 1. At the back of the lever there is a screw *W*, carrying a platinum point *V*. Just below *V* there is another point *U* supported by hard rubber and in connection with the post 2. The extent to which the lever moves is regulated by turning *W*. There should be enough movement to be distinctly felt, but not enough to cause loss of time. The framework of the key (and consequently the contacts *Y* and *V*) is connected to post 3.

Bring the wires from the 4-ampère battery to the posts 1 and 3; notice (by the darkening of the small lamp) that the current passes through the key whenever *Y* and *X* are kept in contact by pressure on the rubber knob *A*.

Bring the battery wires to 2 and 3. Notice that the current passes whenever *V* and *U* are in contact.

[1] To prepare these steel points I procure from the clock factory a flat strip of fine "pendulum wire." Pieces are cut off of 3 cm. length. A hole to fit over the screw is made in each piece; the opposite end is cut to a sharp point and bent. Such a piece is substituted for the usual brass point that comes with the fork. The great elasticity of the steel reduces the friction to a minimum; its hardness keeps the point sharp for a long time, whereby a very fine line may be produced.

[2] See above, p. 82.

[3] The lettering is found on the apparatus. A picture of such a key without the adjusting screws *Z* and *V* is given in The New Psychology, Fig. 27; post 1 is nearest, post 2 is farthest and post 3 between them.

Connect 1 and 2 by a short wire. The current is then interrupted for an instant at each movement of the key downward or upward.

e. Spark coil. The spark coil consists of two coils of wire.[1] The inner one, "primary coil," is made of a few turns of coarse wire ending in the terminals *P*. The outer one, "secondary coil," consists of many turns of very fine wire, ending in the terminals *S*. Insert a metal rod *F* through one of the posts *S* and bring its point within about ½^{mm} of the other post. Bring one wire of the 4A battery to one of the posts *P*. Touch the other post with the other wire for an instant; notice that a spark jumps across at *S*.

Bring one wire of the 4A battery to one of the posts *P* and the other one to the post 2 of the telegraph key. Connect post 3 with the other post *P* by an extra wire. Notice that a spark is produced every time the key knob is pressed or released.

Remove the rod *F* and connect one of the posts *S* to the metallic back of the fork by a light wire and the other one to the binding post *H* of the drum by a similar wire. The wooden base of the fork interrupts metallic connection between the two wires and the spark is forced to fly off the recording point and through the paper to the drum. This makes a white dot on the paper.[2]

f. Condenser. The condenser consists of two sets of sheets of tin-foil arranged alternately. The sets are connected to the two posts *K*, *L*. The sheets are kept separate from each other by sheets of paper. Two wires are brought from *K* and *L* to the posts 2 and 3 of the key without disturbing the battery connections. Notice that the spark at the drum is made stronger by using the condenser.

Experiments.

A. Adjustments. The fork is adjusted at the farther end of the drum. The experimenter sets the drum in motion by striking the edge with his hand. By turning the handle that moves the fork support he pulls the fork along toward him. The speed of the drum should be such that a single wave extends over about 1^{cm}. During the experiment the fork support should move fast enough to make the fork trace a spiral without overlapping, but slow enough not to waste paper. The subject adjusts the key evenly on the table. He then taps several times to prove that the spark connections are in order.

B. Recording the most rapid tapping. The subject takes a comfortable

---

[1] The separable coil should be used, see above, p. 81.

[2] The plan of connection of the spark coil and fork is similar to that shown in Fig. 6 of the New Psychology.

position, grasps the knob of the key between thumb and middle finger, and, steadying the key with the other hand, makes the lever vibrate as rapidly as possible. This is done by way of practice for a few moments without making a record.

The subject is ready. The experimenter calls "Now," whereupon the subject begins to tap as rapidly as possible. The drum is set going and a record is taken for a few seconds. The name of the subject is written in the smoke by a pencil or a pointed stick.

C. Preparing the record. The paper is slit crosswise with a knife, lifted at one end and run through a solution of shellac as described in Ex. VII.

D. Computing the results. When the record is dry a portion about in the middle is selected for computation. As a dot was made at each tap and release of the key, the distance between two dots on the fork-line, or time-line, gives the time for a single movement. The time is divided into 100ths by the wave of the fork-line; the 1000ths are obtained by estimating the extra 10ths of a wave by the eye. Ten successive records are counted. The average and the probable error are found.

Specimen record.

m	v	v^2
40	0.7	0.49
39	1.7	2.89
40	0.7	0.49
42	1.3	1.69
41	0.3	0.09
43	2.3	5.29
40	0.7	0.49
39	1.7	2.89
41	0.3	0.09
42	1.3	1.69
40.7		9)16.10
		10)1.56
		0.16

$\sqrt{0.16} = 0.4 \quad \frac{2}{3} \times 0.4 = 0.3 \quad a = 40.7 \pm 0.3$

Theoretical considerations.

The repeated taps were produced by successive volitions resulting in the alternating movements, down and back. Assuming that the two movements represent two volitions alternated as rapidly as possible, the

result gives the average time required as a minimum for the rise and execution of a volition.[1]

Points to be noted.

1. Regularity and rapidity may be quite different in different persons.
2. A very rapid person may not be a very regular one.

Questions.

1. How are we justified in considering the time between two muscular movements as a mental time? 2. What means would you suggest for shortening the tap-time and decreasing the probable error?

EXERCISE X.—SIMPLE REACTION TO SOUND.

(Needed: recording drum, automatic break, smoking and varnishing arrangements, 100 v. d. electric fork, PFEIL marker, DEPREZ marker, telephone, reaction key, adjustable marker support, simple break switch, two batteries of 1 ampère, one battery of 2 ampères.)[2]

Apparatus.

a. Recording drum. The drum used in this exercise is known as the "standard drum" on account of the steadiness of its movement, which is due to the weight of the wheel.[3] Glazed drum paper of the proper size is adjusted around the drum and is smoked on that quarter which is beneath the projecting arm *C*. The drum is moved by a ratchet handle at the top; it may be stopped by the brake at the side.

[1] The following table gives the results on 20 students in 1896:

Subject:	A	B	C	E	F	G	H	I	I	J	L	M	N	O	P	Q	R	S	U	Z	Averages for all.
Average:	41	71	59	46	80	123	71	92	77	113	97	33	84	72	52	62	147	117	118	60	81
Average variation:	12	24	18	8	9	50	2	28	13	36	11	14	40	10	19	5	20	17	6	3	17
Relative average variation:	39	33	30	17	11	41	2	30	17	32	11	42	48	7	36	7	12	15	5	5	21 per cent.
Probable error:	3.4	6.8	5.1	2.2	2.5	14.0	0.6	7.8	3.6	10.1	3.1	3.9	11.2	2.8	5.3	1.4	5.6	7.8	1.7	0.8	4.5

The results give the times for the alternated movements naturally used by unpracticed persons in attempting to move the telegraph key. By trial the subject can finally select the most rapid movement, which will frequently be much quicker than the original one. The average variation (or mean variation) is the average of the residuals; in the example above it would be the average for the column *v*.

[2] The drum of the previous exercise, which is fitted with an automatic break, may be used for this exercise. The fork and adjustable marker support may likewise be the same as before. In such a case the previous exercise should be put far enough ahead of this one in the course to avoid any need for the same pieces in two simultaneous exercises. It is preferable to have several drums, all of which should have automatic contacts.

[3] See Stud. Yale Psych. Lab., 1895, III, Fig. 16.

b. Automatic break.[1] The projecting arm C as it passes the rubber block D strikes a projecting pin G and moves it. On the other side of D there is the small arm I made into one piece with the pin G; it, therefore, moves when G is struck. This movement brings a platinum point away from the platinum point of the screw H. Thus, if the two wires of an electric circuit are brought to the posts E and F, the current is interrupted every time C strikes G.

c. Marker support. The carriage F riding on the steel post is movable by the handle J. It carries a projecting rod L, to which forks and markers may be attached. When two markers are used, as in the present exercise, an adjustable support[2] M is placed on L. The rod of M is placed vertically. This rod can be rotated by the screw N or lever O.

d. Deprez marker. This marker is adjusted on the rod of the support by the screw P. It is so placed that when it is lengthened, by turning the screw Q, the fine point at the end can be brought into delicate contact with the smoked surface. Bring the two wires from a 1A battery to the posts R, S. Notice that whenever the circuit is completed the armature V is drawn to the magnet U, and that when it is broken the armature flies back. If this does not happen, the adjustment is to be made more delicate by altering the tension of the armature spring at the back or by changing the amplitude of vibration of the armature by moving the cone by means of the screw T.

e. Electric fork. The fork used in this exercise is arranged to vibrate just as that in Ex. IX. The wires from a battery in 1A are brought to the two binding-posts as before. The fork is not attached to the drum, but is placed on the table.

f. Pfeil marker. The PFEIL marker is placed on the adjustable support by means of its clamp in such a way that its point is downward and close to the other marker. The battery wire is removed from one post of the fork and is placed in one of the posts of the marker. A wire is then run from the other post to the fork. Whenever the current passes, the coils of the marker become magnetic and attract the armature D; when the current is interrupted, the armature is released. As the current is made and broken 100 times per second by the fork, the armature vibrates 100 times per second. The vibration is transmitted to the recording point by a connecting bar. The extent of the vibration is regulated by a screw F, which adjusts the distance of the magnets from the armature. The finer adjustment of the point against the drum is accom-

[1] The lettering is on the apparatus; the principle of the automatic break is similar to that shown in Fig. 17.

[2] See above, Fig. 10; for this exercise the clamp M is made of hard rubber.

plished by a screw *G* at the back. The marker is first adjusted so that its point is just above the point of the DEPREZ marker, and then the exact amount of pressure against the drum is attained by *G*. As the drum is turned, a time line is drawn whose waves each indicate 1/100 of a second.

Experiments.

A. Finding the latent time of the Deprez marker. The current is brought to one post of the automatic break, then from the other post to the DEPREZ marker and from the marker back to the battery. The drum is slowly rotated till the arm *C* opens the break and makes a check with the marker. If this is carefully done, the check marks the exact spot at which the break occurs. The carriage is then run down and back in order to draw the zero line, or the line at which the break occurs.

With the PFEIL marker in vibration the drum is now set in rapid rotation. The carriage is then moved downward with sufficient rapidity to keep the records separate. The result is a series of records, each consisting of a time-line and the line drawn by the DEPREZ marker. The paper is removed and varnished. The distance from the zero-line to the check in the marker-line gives, in terms of space, the latent time of the marker at the break; this distance is turned into time by comparison with the time-line. The time is read in 1000ths of a second. Five records are computed to find the average and the probable error.

B. Adjusting the reaction experiment. A new piece of paper is placed on the drum and smoked all around. The PFEIL marker is adjusted as before. The zero-line is made as before.

The 1A circuit through the automatic break is taken from the marker and run through a telephone instead; a click is thus produced in the telephone whenever the arm *C* strikes the point *G*. A switch for turning off the current is inserted in the circuit.

Another 1A current is run through the DEPREZ marker and then through the reaction key. This key comprises two steel rods on which run two rubber slides.[1] The adjustable slide *A* is fastened at any desired place by the nut *B*; the excursion of the movable slide *M* can thus be regulated. For the present experiment the excursion should be about 3 ^{mm}. The index finger is placed in the hole of *M*, the thumb is placed in the hole of *A* and the key is steadied by the third finger. The battery wires are brought to the post of *M* and the post *T* at the top. When the finger is extended, the circuit is closed; as soon as it is moved, the circuit is broken and the DEPREZ marker moves.

---

[1] See Stud. Yale Psych. Lab., 1893 I, Fig. 30. The lettering is on the apparatus.

The subject is comfortably seated with the reaction key in his hand; he must be so placed that he sees nothing of the experimenter's movements.

C. Performing the experiment. The subject is called to attention by telephone clicks produced by tapping the automatic break. The switch is then opened.

The drum is set in rotation; the switch is closed during one revolution, while the carriage is lowered. The telephone click is heard by the subject and the reaction is recorded by the marker. After a few turns of the drum the switch is again closed, while the carriage is lowered as before. As many records as possible are obtained on the drum. The paper is removed and varnished.

D. Computing the results. The average and the probable error are found for the reaction experiments. Since the latent time of the marker is included in the recorded time, its amount must be subtracted in order to find the reaction-time.

Specimen record.[1]

Marker.		Reaction.		
m	v	m	v	v^2
2	0	174	24.7	610.09
2	0	124	25.3	640.09
2	0	156	6.7	44.89
2	0	130	19.3	372.49
2	0	166	16.7	278.89
2	0	141	8.3	68.89
		154	4.7	22.09
		7)1045		6)2037.53
		149.3		10)339.59
				33.96

$$\sqrt{33.96}=5.8$$
$$\tfrac{2}{3}\times 5.8=3.9$$

Latent time of marker, $a=2\sigma$, $r=0$; Reaction-time, $a=149\sigma-2\sigma=147\sigma$, $r=3.9$

[1] Results for 12 students in 1896 are given in the following table:

	Marker. Latent time.	Marker. Average variation.	Subject. Reaction time.	Subject. Average variation.
A	1	0	116	6
B	1	0	146	16
D	0	0	168	24
E	3	0	125	15
F	3	0	143	12
G	3	0	170	27
M	0	0	167	14
N	0	0	152	14
O	1	0	164	31
P	1	0	122	18
Q	2	0	107	20
R	2	0	100	61
Average:	2	0	137	21

The different latent times for the marker are due to different adjustments of the spring.

Points to be noted.

1. The determination of the reaction-time of the subject was closely analogous to that of the latent time of the marker; it would be quite justifiable to speak of the "reaction-time of the marker" or the "latent time of the subject." 2. Since the probable error of the marker was 0, the probable error for the reaction records must be a personal quantity of the subject.

Questions.

1. How would you proceed to determine the latent time for a spark coil? 2. What mental element that was measured in Ex. IX is present in the subject's reaction?

Exercise XI.—Regulated rhythmic action.

(Needed: recording drum, motor, 100 v. d. fork, fork support, automatic make, sounder, break key, spark coil, condenser, smoking and varnishing arrangements, batteries of 1A, 2 and 3A, and 4A.)

Apparatus.

The automatic contact (Fig. 17) is attached to one of the posts of the drum by the screw *E* through the rubber block *V*. A projecting pin in the drum strikes the spring arm *B* and depresses it slightly for an instant.

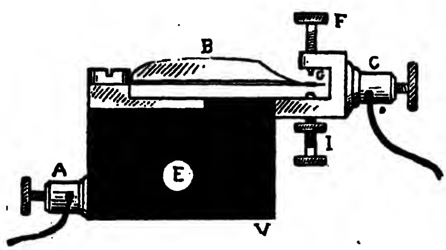


Fig. 17.

The current is brought to the post *A* and passes through the arm *B* to the platinum disc at *G*. Every time the pin on the drum strikes *B* contact is made by *G* against *I* and the circuit is closed. *F* is a screw with a rubber point against which *B* may rest. The automatic make may be turned into an automatic break by interchanging *I* and *F*.

To adjust the position of the automatic contact apparatus the screw *E*

is loosened; it is also so arranged that it can be swung entirely out of the way when not needed.

The remaining apparatus is the same as that used in Ex. VI.

The 2A current is sent through the automatic make and the sounder[1] in series.

The fork is arranged to write on the drum and to be kept vibrating as in Ex. VI.

The 4A current is sent through the break current of the key in the way explained in Ex. VI.

The motor is arranged to run the drum by a belt connecting the two pulleys. The exact rate of speed described is obtained by varying the amount of current sent through the motor.

Experiments.

A. The current through the motor is adjusted so that the drum revolves once a second. This is tested by comparing the clicks during a number of seconds with the indicated seconds of a watch. Then the subject, seated near the sounder and away from the drum, taps on the key knob in time with the clicks. A record is taken during about 15^s.

B. The drum is adjusted to revolve twice a second, and another record is made.

C. The drum is adjusted to revolve three times a second, and a record is made.

With a full-width paper on the drum all the experiments can be obtained on one sheet.

D. The zero-line is found as in Ex. VII.

E. Varnish and dry the paper.

F. Read ten successive results to the 1/1000 sec. in each record; distances to the left of the zero-line are —, to the right +.

G. Compute the constant errors (the latent time of the sounder is subtracted) and the probable errors (see Ex. III).

[1]The sounder has an electric contact arranged to close a circuit at the moment it strikes (a telegraph relay may be used). Its latent time for a current of 2 ampères can be determined and marked on it. A convenient way of determining the latent time is to connect the contact of the sounder with the wires from *C* of the battery in Fig. 7, while the wires from *G* are connected to the primary poles of the spark coil. The condenser is also attached to the primary poles. As the contact points of the sounder strike, the current which passes through *B*, *G* and the coil, is short circuited; this is practically equivalent to its being interrupted; a spark record is therefore made as usual.

Specimen record.[1]

Speed 1. m	v	v^2	*Speed 2.* m	v	v^2	*Speed 3.* m	v	v^2
+51	6.0	36.00	+10	7.6	57.76	−5	3.3	10.89
+39	6.0	36.	−7	9.4	88.36	−2	0.3	0.09
+40	5.0	25.	+6	3.6	12.96	−3	1.3	1.69
+47	2.0	4.	+15	12.6	158.76	+1	2.7	7.29
+41	4.0	16.	−12	14.4	207.36	−3	1.3	1.69
+53	8.0	64.	+3	0.6	0.36	−4	2.3	5.29
+50	5.0	25.	−1	3.4	11.56	−5	3.3	10.89
+41	4.0	16.	−7	9.4	88.36	+1	2.7	7.29
+44	1.0	1.	+8	5.6	31.36	+2	3.7	13.69
+44	1.0	1.	+9	6.6	43.56	−1	0.7	0.49
+45.0		9)224.00	+51		9)700.40	+4		9)59.30
		10)25.00	−27		10)77.82	−23		10)6.59
		2.50	+2.4		7.78	−1.7		0.66

Speed 1	Speed 2	Speed 3
$\sqrt{2.50}=1.6$	$\sqrt{7.78}=2.8$	$\sqrt{0.66}=0.8$
$\frac{2}{3}\times 1.6=1.1$	$\frac{2}{3}\times 2.8=1.9$	$\frac{2}{3}\times 0.8=0.5$
$a=+38.0\pm 1.1$	$a=-46\pm 1.9$	$a=-87\pm 0.5$

Points to be noted.

1. There is a continual estimate of the time interval and an anticipatory reaction; this estimate is corrected every time by occurrence of the sound. 2. The signs of + or − for the constant errors and the largeness or smallness of the probable errors are quite different for different subjects.[2] 3. One of the speeds is specially favorable to regularity.

[1] The following table gives the results for 13 students in 1896:

	Speed 1. Constant error.	Average variation.	Probable error.	*Speed 2.* Constant error.	Average variation.	Prob. error.	*Speed 3.* Constant error.	Average variation.	Prob. error.
A	+ 51	25	7.0	−28	9	2.5	+20	19	5.3
B	+ 44	75	21.0	−84	32	9.0	− 9	20	5.6
C	− 53	22	6.2	−23−	19	5.3	+75	17	4.8
D	+ 14	57	16.0	−42	15	4.2	+ 2	18	5.0
E	− 31	19	5.3	−30	17	4.8	−10	7	2.0
F	− 57	32	9.0	−20	10	2.8	−25	10	2.8
I	− 57	25	7.0	+36	33	9.2	−33	19	5.3
J	−105	37	10.4	−57	13	3.6	−86	20	5.6
O	+ 12	60	16.8	+10	19	5.3	+37	30	8.4
Q	+ 29	19	5.3	+10	7	2.0	+25	7	2.0
R	+ 15	20	5.6	− 8	11	3.1	+14	6	1.7
S	− 28	114	31.9	−86	16	4.5	− 5	7	2.0
T	+ 72	41	11.5	−89	83	23.2	−40	5	1.4

[2] See New Psychology, 182.

Questions.

1. How should these experiments have been performed in order to eliminate practice and fatigue? (See Ex. III, etc.) 2. A comparison of the results with each other and with those of other individuals would be likely to give some information of a person's mental constitution in regard to promptness and reliability of response; what conclusions do you draw from your record?

Exercise XII.—Simple and complex reaction-time.

(Needed: recording drum, 100 v. d. fork, fork support, multiple key, 2 condensers, reaction key, telephone, resistance box, switch, telegraph key, sounder, 3 batteries of 1A, one battery of 4A.)

Apparatus.

a. Recording drum, spark coil, condenser, fork, fork support, reaction key. See Exercises IX, X and XI.

b. Multiple key.[1] This is a key having two levers, the upper one supported on a rod with center-bearings and the lower one on the rod as an axle. They are carefully adjusted so that both rotate around the same axial line. The upper lever is held down at the back by an adjustable spring; the position and the extent of its movement are regulated by two adjusting screws that strike short upright rods. In front of the axis there are two contact screws on the upper lever. Opposite to them there are two platinum points on the lower lever. Either one of the upper screws can be made to strike the opposite point on the lower lever. If a circuit is brought to a contact screw and its opposite point, it will be closed whenever the upper lever is pressed downward. The current from a 1A battery is brought to the two binding-posts connected with such a pair of contacts, and the closing of the circuit is observed.

At the back of the lower lever there are two contact screws opposite the contact points in the base. The rearmost of these screws is turned somewhat more than the other one; it will then rest on its contact point owing to the pressure of a spring in front. The 4A current is sent through the contact. Whenever the knob of the key is pressed so that the front contact is made, the rear contact is broken. Thus the 4A circuit is broken at the moment the 1A circuit is made.

The spark coil is placed in the 4A circuit and the condenser is arranged around the break, as in Ex. IX. Observe that each pressure on the knob makes a spark on the drum.

[1] See above p. 81.

Insert the telephone in the 1A circuit. Observe that a spark is made whenever the telephone clicks.

Insert the reaction key with a condenser in the 4A circuit. Observe that a spark is made whenever the reaction occurs.

Observe that after the 4A circuit is broken by the multiple key no spark is made by the reaction key. This circuit must, therefore, be closed again after the break by the multiple key. At the front of the lower lever there is an adjustable contact point which dips into a cup of mercury covered by water. Connect the framework of the key to one of the posts for the back contact and the mercury cup to the other one. Adjust the contact point so that it is just above the surface of the mercury. Observe that as the key is depressed the 4A circuit is broken and then immediately closed again, so that it is ready for a break by the reaction key.

There are thus two sparks made; one at the moment of the telephone click and another at the moment of reaction. By laying wires from the secondary poles of the coil to the fork and the drum, as in Ex. IX, a record of the time between these two sparks is obtained.

c. Telephone, resistance and switch. The telephone has already been inserted in the 1A circuit; a shunt switch is now inserted in the same circuit. The wires are brought to the two binding posts; when the switch is closed the current can pass through the telephone, but when it is open the current cannot pass. A resistance box (or a length of resistance wire) is connected around the switch, i. e., its two poles are connected to the two posts of the switch. When the switch is now opened, the current can pass by way of the resistance, which is adjusted so that the sound from the telephone is weakened. When the switch is closed the current can pass in practically full strength through the telephone and produce a loud sound.

d. Sounder and key. An independent circuit is made to pass through a telephone sounder and a telegraph key; a pressure on the key produces a click of the sounder.

e. Arrangement. The multiple key is placed beside the drum so that the right hand can manipulate it readily while the left hand turns the handle of the marker-support on the drum. The telegraph key is placed beside the multiple key. The switch is placed just beyond.

Long wires are now inserted in the recording circuit (multiple key and reaction key), in the stimulus circuit (multiple key and telephone) and in the warning circuit (telegraph key and sounder) so that the reaction key, telephone and sounder may be taken to a distant part of the room (or another room).

Experiments.

A. Reaction with continuous expectation. The experimenter sets the drum in rotation and then taps a few times on the telegraph key. The switch is left closed. The subject holds the telephone to the ear and takes the reaction key in the hand as in Ex. X. He is to be constantly attentive and to react whenever the telephone clicks. The experimenter begins to move the marker carriage slowly and continues to do so while he presses the multiple key. Two sparks will be seen, one from the multiple key and one from the reaction key; the multiple key is then released and the movement of the carriage stopped. The experiment is repeated for about 10 times at intervals of about 15^s.

B. Reaction with specialized expectation. The experimenter proceeds as before, except by giving a warning signal on each occasion about $2\frac{1}{2}^s$ before the stimulus is produced. This he doos by tapping the telegraph key before pressing the multiple key. The subject is not to expect the telephone sound except when warned by the sounder. Ten experiments, as before.

C. Reaction with discrimination and choice. The subject is to react to the weaker sound and not to the louder one. The experimenter produces them in irregular order by manipulating the switch before each experiment. The procedure is as in *C.* Ten experiments.

Computation.

The record sheet is removed from the drum and varnished as in Ex. VII. The latent time of the sounder (known from Ex. XI) is allowed for as each recorded is counted. The averages and probable errors are calculated. Denote the averages by a, b and c, and the probable errors by r_a, r_b and r_c. Find $p = b - a$, $q = c - b$, $s = r_b - r_a$, and $t = r_c - r_b$. The quantity p gives the lengthening (+) or shortening (—) in the reaction-time due to the specializing of expectation; s gives the increase (+) or decrease (—) in irregularity for the same cause; q gives the lengthening due to the introduction of additional mental processes; and t gives the increase in irregularity for the same cause.

Points to be noted.

1. To eliminate progressive and other errors the phenomena *A*, *B* and *C* should be investigated in pairs; thus on one occasion *A* and *B* should be investigated, and *B* and *C* on another. 2. More mental labor is required of the subject in *A*.

Questions.

1. In determining the difference between A and B, how would you proceed in order to avoid progressive errors? 2. In determining the difference between B and C, on what system would you arrange the experiments in order to equalize differences that might arise from employing two intensities of sound?

EXERCISE XIII.—TIME ESTIMATES.

(Needed: kymograph, contact attachment, 2 MEUMANN contacts, 250 v. d. fork, fork box, 10 v. d. fork, MAREY recording tambour, induction coil, telephone, key, spark coil, condenser, plain recording point, 1A battery, 4A battery, smoking and varnishing arrangements, cross-section paper.)

Apparatus.

a. Kymograph. As in Ex. VIII.

b. Contact attachment.[1] The support is screwed to the base of the kymogragh. The projecting gear wheel is adjusted to fit to the gear wheel that has been placed on the axle of the kymograph. As the kymograph moves, the arm on the contact attachment passes over the graduated circle.

c. Meumann contact.[2] A metallic star with six arms is held to a rubber block by a screw in the center. At each rotation of the projecting arm it strikes an arm of the star and rotates it by 1/6 of a revolution. Three of the arms bear small screws which touch two metallic points sunk in the rubber block. The rubber block is fixed to the circle of the contact attachment by the projecting screw.

Let the circuit from the 1A battery be sent through the back binding-post and the left-hand side post of a contact. The circuit is completed every time an arm bearing a screw passes over the sunken contact, and is broken every time the screw arm is moved off. Consequently the central arm alternately closes and opens the circuit as it passes this block. If a current producing a tone were sent through this contact, the tone would alternately be turned on and off. A red mark on the block opposite the graduated circle serves to indicate when the circuit is closed.

The second contact is connected in series with the first one. The two side posts of this contact are connected together; the circuit is broken when the arm of the star moves, but is immediately closed again by a

[1] Fig. 236 in WUNDT, Physiol. Psychol., II 424, Leipzig, 1893.

[2] Fig. 5 in MEUMANN, *Beiträge zur Psychologie des Zeitbewusstseins*, Philos. Stud., 1896 XII 147.

contact point reaching the second sunken contact. A white mark on the block indicates when the circuit is broken.

Consequently: 1. the current passes through the second block only when it passes through the first one, i. e., at alternate revolutions of the central arm; 2. the current, when passing, is broken for a brief instant at the second block.

d. 250 v. d. fork. Same as 100 v. d. fork of Ex. IX, except in the rate of vibration, which is 250 times a second.

e. Fork box. This is a box padded with felt. Wires from the inside are brought to binding posts on the outside. The fork is put in the box and connected to the wires.

f. 10 v. d. fork. This fork, vibrating 10 times a second, is hung from a strong support. One prong carries a sliding collar connected by a small link to the metal disc on the top of a tambour. As the fork vibrates, the movement is mechanically transmitted to the air of the tambour. The amplitude of the movement of the top of the tambour is regulated by moving the collar along the prong. The tension of the rubber top is adjusted by means of the jamb nuts that clamp the tambour to the support.

g. Marey recording tambour. As in Ex. VIII.

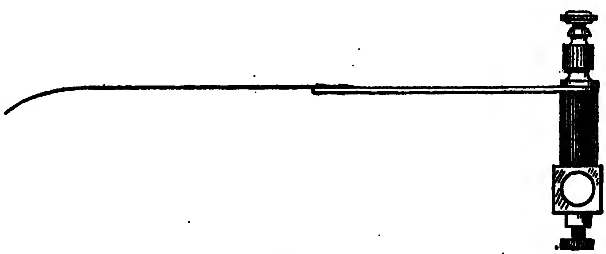


FIG. 18.

h. Induction coil. This consists of a short primary circuit of coarse wire (red) and a longer coil of thinner wire (green). The two coils are not connected; the secondary one is loose and can be placed anywhere.

i. Key. The key of Ex. IX is used; only the rear (or break) contact is employed. The condenser is connected to the key around the break.

j. Spark coil. As in Ex. IX.

k. Plain recording point. A brass arm terminated by a flexible steel point of pendulum wire is attached to a small rubber block by a thumb screw (Fig. 18). The opening through which the screw passes is elongated to allow adjustment of the point lengthwise. During the experiment the point is adjusted to lightly touch the surface of the drum.

l. Smoking and varnishing. As in Ex. VII.

m. Timing the drum. The MAREY tambour is adjusted so as to write on the drum. The tube is connected with the tambour of the 10 v. d. fork. A blow is struck on one prong of the fork and the tambour-point vibrates 10 times a second. As the drum revolves, the time line is drawn on it. Adjust the drum to revolve once in 9 seconds.[1]

n. Adjustment of the tone. Bring one of the wires from the 1A battery to the fork by way of the fork box und from the fork through the primary circuit of the induction coil back to the battery. Connect the ends of the secondary coil to the telephone and lay the coil beside the primary one. A tone is heard in the telephone when the fork is set vibrating.

Break into the telephone circuit and by extra wires insert the star contacts (which have already been connected together as described under *c*). When the kymograph is running, a tone will be turned on and then interrupted for an instant; this occurs at alternate revolutions.

o. Adjusting the spark record. The current from the 4A battery is run through the break key and through the primary circuit of the spark coil. The condenser must be connected around the break. The simple recording point is connected to one of the secondary poles, the drum to the other. Whenever the key is tapped, a spark flies from the point to the drum.

p. Drawing the zero-lines. Place the first contact with its red mark at 0°. Loosen the back screw *B* (see Fig. 17) of the kymograph. Turn the drum slowly till the tone is first heard. Draw a zero-line by lowering the drum axially by the handle *H*. This line indicates the moment at which the tone begins. With the second contact at 40° turn the drum further until the tone has been interrupted and just begun again; draw another zero-line, which indicates the moment at which the second tone begins. Place the second contact at 80° and then at 120° and draw zero-lines as before.

Experiments.

A. Measuring the time estimate for a tone of one second. Place the contacts so that the red and white indicating points are 40° apart. This will give a tone lasting one second, then a moment's interruption (1/8 of a sec.) and thereafter another tone.

The subject is seated with eyes closed. The kymograph is set in motion. The tone begins, is interrupted for an instant and is begun again. When the subject thinks that it has lasted as long after the

[1] If desired, the drum may be timed by a watch, by the method used in Ex. VIII. or by an electric fork.

interruption as it did before, he presses the key. After a few preliminary experiments for the sake of practice, the experimenter lowers the drum slightly (by the small handle at the top) after each experiment. Six records are taken.

B. Measuring the time estimate for two seconds. The contacts are placed at 80° apart and the experiments are repeated. Six records.

C. Measuring the time estimate for three seconds. The contacts are placed 120° apart. Six records.

D. Measuring the time estimate for four seconds. The contacts are placed 160° apart. Six records.

Computation.

Cut off a piece of the time-line. Use it as a scale, reading the 10ths of a second and estimating the 100ths. The records for 1 second are placed in the first column, those for 2 seconds in the fourth column, etc. The average is found for each column. The probable errors are also computed.

Let the standard interval be indicated by T and the interval as estimated by t. Find the constant error $c = t - T$ for each value of T. Thus for $T = 1$ sec. and $t = 85$, $c = 85 - 100 = -15$.

In this way two series of values, the constant error c and the probable error r, are obtained for the series of values used for T[1]. Put $c = f(T)$ and $r = F(T)$, as explained in Ex. III. Plot the curves for these functions as explained in Ex. I. and II.

Points to be noted.

1. Note the tendency to underestimate long intervals of time. Extremely short intervals are overestimated. 2. The reaction-time is not

[1] Results for 9 students in 1896 are given in the following table. In this case the time was measured from the beginning of the first tone to the beginning of the second.

	1 Sec.			2 Sec.			3 Sec.			4 Sec.		
	Const. error.	Aver. var.	Prob. error.	Const. error.	Aver. var.	Prob. error.	Const. error.	Aver. var.	Prob. error.	Const. error.	Aver. var.	Prob. error.
C	+17	13	3.6	+69	8	2.2	+81	20	5.6	+84	26	7.3
G	+21	13	3.6	—28	20	5.6	—73	12	3.4	—109	15	4.2
I	—23	10	2.8	—22	36	10.1	—57	50	14.0	— 86	40	11.2
K	+ 1	9	2.5	—52	9	2.5	—70	20	5.6	— 49	18	5.0
O	—66	4	1.1	—88	10	2.8	—28	22	6.2	— 50	28	7.8
P	—23	8	2.2	+41	27	7.6	—63	21	5.9	—135	42	11.8
R	— 7	11	3.1	+27	15	4.2	+ 3	12	3.4	— 7	18	5.0
S	+25	14	3.9	+11	28	7.8	—87	8	2.2	—149	18	5.0
T	—13	12	3.4	—92	21	5.9	+35	62	17.4	—104	37	10.4

to be subtracted from the second interval, because the subject involuntarily times his movement to occur at the point desired; see Ex. XI.

Questions.

1. These experiments are frequently referred to as being on the "time-sense" or "time-consciousness." How would you define such a term scientifically? Compare Ex. IV (Point 2). 2. What mental characteristics would be indicated by a large negative constant error and a large probable error?

EXERCISE XIV—COMPLEX REACTION-TIME.

(Needed: pendulum chronoscope.[1])

Apparatus.

An accurately adjusted double-bob pendulum is held by a catch at the right-hand side. The light pointer is caught on the projecting arm of the pendulum.

The chronoscope is first leveled by placing a spirit level on the base in a line parallel to the front; the screws of the two fore-legs are turned till the bubble of the level is in the middle. The level is then turned at right angles, and the screw of the rear leg is turned.

The large milled head in front is turned clockwise as far as it will go, thereby closing the shutter and setting the reaction button at the back.

When the experimenter presses the release at the right, the pendulum swings forward, releasing the shutter by striking a pin opposite the place where the pointer indicates zero. When the subject presses the reaction button, a horizontal bar behind the pointer clamps it to the scale. The graduation on the scale gives the time between the fall of the shutter and the pressing of the button. This scale is established by direct comparison with fork records on the drum in a manner similar to methods employed in Ex. VII. The figures on the scale indicate 100ths of a second; in this exercise the readings are to be in 100ths, not 1000ths.

In executing an experiment the pendulum is placed at the right, the pointer is carefully caught on it, and the milled head is turned. Red and white slips are inserted alternately in the vertical exposure wheel. The subject is comfortably seated with his finger on the reaction button; he is to press the button as soon as the shutter drops. The pendulum is released and the experiment is made; this is repeated until familiarity with apparatus and method is attained. The experimenter says "Now" about two seconds before each experiment.

[1] See Stud. Yale Psych. Lab., 1895, III 98, and New Psychology, Ch. IX.

The individual experiments should be separated by about 10 seconds; the groups by at least 30 seconds. When a group is begun, three or four experiments should be first taken without making any record of them. The subject must not know his results.

Experiments.

A. Simple reaction. The exposure wheel is turned so that a red slip is behind the shutter. The subject knows the color to be shown; he is to press the button just as soon he sees it. Five records are taken; the results are placed in the column m_1.

B. Reaction with discrimination. The subject is to react every time as before, but is to see the color distinctly before reacting. The experimenter at each experiment gives the exposure wheel a twirl, letting it stop on whichever notch it happens to strike. If it stops between two colors it is turned to the next notch. The presentation of the colors is thus a matter of chance. Five records are made; column m_2.

C. Reaction with discrimination and choice. The subject is to react only to red; for white he is to remain still. The wheel is twirled as before. Five records are made. An account is also kept of the number of mistakes; column m_3.

D. Same as *C*, but with reaction to white and rest to red column m_3.

E. Same as *B*; column m_2.

F. Same as *A*, but with white instead of red; column m_1.

The simple reaction time is composed of two mental processes, sensation and volition. The extra process introduced in experiments *C.* and *E.* is known as discrimination; the average for m_1 substracted from that for m_2 will give the discrimination time. The process introduced in *B.* and *D.* is known as choice; the average for m_2 from that for m_3 will give the time of choice.

Specimen record.

m_1	v_1	v_1^2	m_2	v_2	v_2^2	m_3	v_3	v_3^2
21	0.1	0.01	29	0.1	0.01	35	4.9	24.01
22	0.9	0.81	30	1.1	1.21	34	5.9	34.81
20	1.1	1.21	29	0.1	0.01	39	0.9	0.81
22	0.9	0.81	28	0.9	0.81	41	1.1	1.21
23	1.9	3.61	27	2.9	8.41	32	7.9	62.41
21	0.1	0.01	29	0.1	0.01	42	2.1	4.41
21	0.1	0.01	32	3.1	9.61	37	2.9	8.41
20	1.1	1.21	35	6.1	37.21	35	4.9	14.01
20	1.1	1.21	29	0.1	0.01	30	9.9	98.01
21	0.1	0.01	28	0.9	0.81	44	5.1	26.01
21.1		9)8.90	28.9		9)58.10	39.9		9)284.10
		10)0.99			10)6.46			10)31.57
		0.09			0.65			3.16

$\sqrt{0.09} = 0.3$	$\sqrt{0.65} = 0.8$	$\sqrt{3.16} = 1.8$
$\frac{2}{3} \times 0.3 = 0.2$	$\frac{2}{3} \times 0.8 = 0.5$	$\frac{2}{3} \times 1.8 = 1.2$

Simple reaction-time : $a_1 = 21.1$, $r_1 = 0.2$.
Reaction with discrimination : $a_2 = 28.9$, $r_2 = 0.5$.
Reaction with discrimination and choice : $a_3 = 39.9$, $r_3 = 1.2$.
Discrimination-time, $d = a_2 - a_1 = 7.8$.
Choice-time, $c = a_3 - a_2 = 11.0$.

Points to be noted.

1. The empirically established scale takes up the errors of the apparatus. 2. The results d and c are termed "discrimination-time" and "choice-time;" these terms are to be defined by giving the manner in which the results were obtained. They are not to be defined as the times required for the execution of two processes known as discrimination and choice which are defined in some other way. 2. We would expect that $a_3 - a_1 = d + c$, but this will rarely happen in performing the exercise owing to unavoidable sources of error in the untrained subject.

Questions.

1. What would probably have been the change in the results if the experimenter had arbitrarily placed the colors instead of allowing the selection by chance and if the subject had known this fact? 2. Why is the probable error larger for a_3 than for a_2?

Exercise XV.—Association-time.

(Needed: pendulum chronoscope, cards with words, chin key, 2A extra-circuit battery.)

Apparatus.

a. Pendulum chronoscope. See Ex. XIII. An electromagnet beneath the base is arranged to operate the reaction-key whenever the current is sent through it. The poles are at the posts marked *C* and *D*.

b. Cards with words. Two sets of small cards for the exposure wheel are placed beside the apparatus. One set is to be used by each experimenter; it must not be seen by the subject; therefore the boxes containing the sets are not to be opened until everything has been arranged for taking records.

c. Chin key. This is the modified telegraph key of Ex. IX., arranged for a break contact only, as in Ex. XII. It is mounted on blocks so as to be just below the chin of the subject. The current from the 2A battery is brought to the posts *C, D*. This causes the straight bar behind the chronoscope scale to clamp the pointer.

The back contact of the key is now similarly connected with the battery. As contact is made as long as the key is untouched, this acts as a "shunt" and the current passes through the key (almost entirely) rather than through the longer and more difficult circuit of the magnet. Consequently the magnet does not act until the key is touched.[1]

The subject is comfortably seated so as to see the exposure opening. The key is adjusted to bear lightly against his chin.

Experiments.

A. Sensory motor association. The experimenter opens the box containing the cards, and, out of sight of the subject, inserts one of them in the exposure wheel. When the shutter falls and exposes the word the subject is to repeat the word aloud, always emphasizing the chin movement so as to move the key knob. Three or four experiments are taken in order to give practice. Thereafter the wheel is filled with 10 new cards. Five records are made.

B. Association of ideas. Leaving the same cards in the wheel the subject upon seeing a word is to call out the first other word that occurs to him. Several experiments are made for practice. Ten new cards are then inserted and five records are taken. After each record the pair of associated words is written.

C. Fill the wheel with ten cards more and make five records on association of ideas as in *B.*

D. Fill the wheel with ten cards more and make five records on sensory motor association as in *A.*

Computation.

Find the average and the probable error for each kind of association. If we assume that in the association of ideas an extra mental process is directly added to the sensory motor association, the time for this process is found by subtracting the time for sensory motor association from the gross association-time as recorded.

Points to be noted.

1. Note that the larger characteristic variations, as compared with Ex. XIII, may indicate any or all of the following sources: 1. complexity of the processes; 2. presence of disturbing influences; 3. vagueness in the definitions; 4. inadequacy of the methods of experimenting.

2. Note that the subject is not told to associate as quickly as possible.

[1] With a lamp battery the connections are made as in Fig. 7; the wires from socket *G* are brought to the magnet and those from socket *C* to the key.

Questions.

1. What is the relation between simple reaction and sensory motor association? 2. Why is the latent time of the magnet left undetermined?

EXERCISE XVI.—REPRODUCTION OF A TONE BY THE VOICE.

(Needed: 100 v. d. fork, spark coil, condenser, PULUJ tube, simple switch, disc with graduated series of dots, manometric flame with mouthpiece, motor with lamp board, 4A battery.)

Apparatus.

a. Electric fork. The current from the 4A battery is run through the fork in a manner similar to that for the battery through the fork in Ex. IX. To diminish the spark the poles of the condenser (Ex. IX) are connected to the fork at each side of the break, i. e., at the points closest to the platinum wire and the platinum disc. One of these points is the binding post at the back of the fork (it could not be closer without interfering with the vibration of the fork); the other is at a screw on the brass base supporting the platinun disc (not at the binding post at the end of the magnet wire).

b. Spark coil and Puluj tube. One of the wires is removed from the fork and brought to one of the primary poles *P* of the coil (Ex. IX); the other pole *P* is connected to the fork. The current thus runs through the primary circuit of the coil; as it is interrupted by the fork 100 times per second, 100 sparks occur at the poles of the secondary coil.

The poles of the secondary coil are connected to the posts of a shunt switch (Ex. XII). Thread-like wires are led from this key to the poles of the PULUJ tube.

The PULUJ tube is a vacuum tube having between the electrodes a mica plate coated with a phosphorescent substance. When the short circuiting key is open, this surface gives a flash of light at every break in the primary circuit; consequently, when the fork is vibrating, it flashes 100 times a second. If the flash is not strong, reverse the wires at the poles.

c. Disc with dot scale. A disc of cardboard is marked with 21 rows of dots, each row differing from the next by one dot.[1] The disc is placed on the axle of a motor, to which the current is supplied by a lamp-board, When the disc is put in rotation the dots fuse into a set of gray rings. The room is darkened and the PULUJ tube is placed close to the disc so as to illuminate it. At a certain speed of the disc one of the rings will reappear as a series of dots at rest; according to the laws of stroboscopic

[1] Fig. 19 is a reduced copy of the original disc which is 75 cm. in diameter. Although rather small, Fig. 19 can be cut out and used on the motor.

vision there must then be 100 dots in that ring passing by the tube in one second. The neighboring rings will also break up into dots, but the dots will appear in motion; those in which less than 100 pass per second will appear to move backward, while those in which there are more will move forward. It will sometimes happen that no ring will pass exactly 100 dots; a touch on the axle will then slightly diminish the speed. The speed of the motor is adjusted by varying the amount of current.

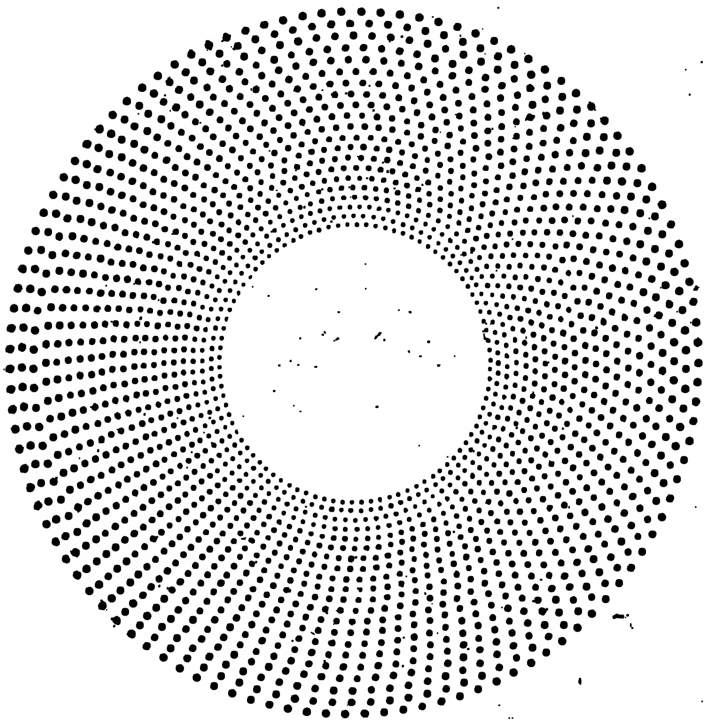


FIG. 19.

d. Manometric flame. Illuminating gas is brought to the front part of a capsule (Fig. 20) from which it issues as a small jet; the size of this jet is regulated by a small stopcock. The back of this capsule is formed by a thin membrane. Back of this membrane is a small chamber opening into a trumpet-shaped mouthpiece. Upon singing into this mouthpiece the membrane is made to vibrate by the vibration of the air producing the tone. The gas in the capsule is likewise set in vibration, whereby the flame alternates between maximum and minimum of size with every vibra-

tion. These vibrations of the flame can be seen by moving the eyes suddenly sidewise. The vibrations produce periods of light and darkness just as in the case of the PULUJ tube. Thus if a tone of 100 vibrations be sung, there will be 100 flashes per second. By holding the flame close to the rotating disc that series of dots can be picked out in which the number of dots passing corresponds to the number of vibrations in the flame.

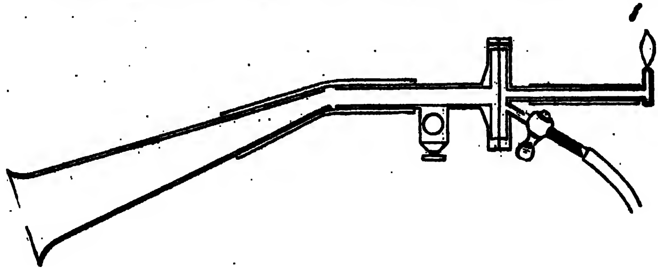


FIG. 20.

Experiments.

The experimenter is to pick out the 100 row of dots, i. e., the one which appears to remain motionless when illuminated by the PULUJ tube. The subject, holding the capsule in his hand, is to sing the same tone as the fork. While doing this he is to move the flame along in front of the disc until he finds the row of dots showing the number of vibrations in the tone sung. The experimenter records the number of rows by which this one differs from the correct one; toward the center is —, toward the outside +. A difference of 1 row means an error of 1 vibration in singing the tone.

The octave of the fork-tone is sung and the error is noted as before. A difference of one row means an error of two vibrations.

Ten records are made on each point. Averages and characteristic variations are calculated.

EXERCISE XVII.—COLOR LAG.

(Needed: electric color wheel with speed indicator, black and red MAXWELL discs, backing disc, circular scale and paper ring for discs, small telescope on GAUSS tripod, battery of 2A, simple switch, 32 c. p. lamp, tape measure.)

Apparatus.[1]

a. Color discs. A red and black disc are slipped together by means of the radial slits. The backing disc is an unslit one which is placed

[1] See Stud. Yale Psych. Lab., 1895 III 102, Fig. 17, for a view of the discs, motor, speed indicator and connections.

behind the others in order to keep the edges from flapping when they are rotated.

b. Color wheel. The essential is a rapidly rotating axle with a screw-nut for fastening the discs against a flange. This is best obtained by using an electric motor. For the present exercise the motor is series-wound in order that its speed may be controlled by the amount of current. The current is brought to the two posts of the motor, passing in its way the two poles of a shunt switch. When the switch is closed the current passes directly across without going through the motor; when it is open the current is forced to pass through the motor.

c. Speed indicator. The rotation of the motor axle causes the indicator arms to revolve and to fly outward. The extent to which they move outward depends on the relation of the speed of revolution to the weight of the arms and the tension of the restraining springs. A pointer is connected with the indicator to show just how much the arms move. The pointer moves over a scale graduated to show the number of revolutions per second. The scale was established empirically by spark-records on the drum, after the manner of Exercise IX, the place of the key in that exercise being taken by a revolving pin at the end of the axle striking against a metal spring.

d. Telescope. This may be a simple tube blackened inside; it limits the amount of the disc seen to a circle of definite area. Or a simple reading telescope of the usual kind may be used. It is placed on the tripod.

e. Adjusting the apparatus. The nut is removed from the color wheel. The backing disc is placed on the axle. The red and black discs are slipped together, so that when rotated they will not catch the wind; if the motor rotates counter-clockwise the edges must overlap to the right. The discs thus slipped together are placed on the axle, a small paper ring is placed in front and the nut is partly screwed up. The circular graduated scale is laid over the discs and they are moved till each occupies half the circle. The nut is then screwed tight.

The battery is turned on and the motor started.

The 32-c. p. lamp is lighted and placed at ½ meter in front and slightly below the discs.

The Gauss tripod is placed at a distance of 1 meter from the motor. The telescope is then adjusted so that the eye sees the whole field of view as a colored circle.

Experiments.

The motor being at rest and the subject looking through the telescope, the experimenter says "Ready" and sends the current through the motor,

The subject sees the color alternate with black, at first slowly, then rapidly. Soon they appear to mix, but still retain a flickering appearance. As the speed continues to increase, the flickering becomes less marked and finally diappears. At the moment when the illumination of the field appears to be constant and steady the subject says "Now." The experimenter notes and records the position of the pointer at this moment.

The speed of the motor is allowed to increase considerably beyond the point just recorded; the current is then turned off. The speed gradually decreases and at some point the illuminated field begins to flicker. At this point the subject says "Now," and the experimenter notes and records the position of the pointer.

Records of the first kind may be called "up-records," those of the other "down-records." The up-records are placed in one column, the down-records in another.

After a few preliminary experiments to obtain practice, ten records are made of each kind.

Computation.

Let m be the average of the up-records and n that of the down-records. The time of one revolution in seconds is thus $1/m$, or $1/n$, and the time of half a revolution in $\frac{1}{2}m$ or $\frac{1}{2}n$.

Let the suppositions be made: 1, that the black was equivalent to absence of light; 2, that there was no lag at the appearance of the red. It follows that since the red seemed to be present all the time, whereas it was present only half the time, the sensation must have persisted through the time of ½ a revolution, i. e., $2m$ or $2n$ sec., without any perceptible diminution of intensity.

The suppositions are not strictly according to fact. The black of the disc is not an absolute black, and there is a small lag at the beginning of the red sensation. For a bright red and a cloth black these errors may be neglected, as in the present case.

Below the records the following statements are to be made (all figures being in decimals to the 1/100 and the unit being seconds): lag, up, = ; lag, down, = ; lag, average, = .

Points to be noted.

1. The lag may be dependent on the intensity of the light and the area of the field. 2. The lag is a psychical and not a physical affair.

Questions.

1. Would you add or subtract the latent time (or lag of the color at the beginning), if it were known and you wished the true time of lag? Why? 2. What is the unit of measurement in this exercise?

NOTES.

As this number of the Studies has, for various reasons, been delayed beyond its usual time, it was considered advisable to bring references, etc., down to 1897.

The following list will supply the information, not previously given, concerning the occasions of the various articles published in the Studies. An article as published is condensed and corrected from the original thesis.

1. Theses for the degree of Ph.D.: *Investigation in reaction-time and attention*, by C. B. BLISS; *Researches on the mental and physical development of school-children*, by J. A. GILBERT; *Measurements of illusions and hallucinations in normal life*, by C. E. SEASHORE; *Studies of fatigue*, by JOHN M. MOORE.

2. Theses for the degree of M.D., the work being done under the direction of the Psychological Laboratory and presented to the faculty of the Yale Medical School: *On the relation of the reaction-time to variations in intensity and pitch of the stimulus*, by M. D. SLATTERY; *Reaction-time in abnormal conditions of the nervous system*, by ALFRED G. NADLER; *Simple and cortical reaction-time*, by HOWARD F. SMITH.

3. Theses for special honors at graduation from Yale College, the theses being frequently made parts of larger articles: *Experiments on the highest audible tone*, by HOWARD F. SMITH; *Some experiments on the reaction-time of a dog*, by EDWARD M. WEYER; *Researches on reaction-time*, by JOHN L. BURNHAM; *Researches on reaction-time*, by A. E. VON TOBEL; *Researches on reaction-time*, by A. SILVERSTEIN; *Researches on reaction-time*, by G. R. HOLDEN; *Researches on voluntary effort*, by H. R. MCDERMOTT.

The regular courses given each year in the laboratory are as in the following list. The amount of direct personal supervision over the work of a student in a course can be roughly inferred from the total number in that course; the total for the present year is stated after each course.

1. *Physiological and Experimental Psychology.* Two lectures per week throughout the year. The material covered by the demonstrations and experiments is about that contained in Ladd's Outlines of Physiological Psychology and Scripture's New Psychology. 127 seniors and juniors (elective), 8 graduates, 3 specials.

2. *Elementary Laboratory Practice.* One exercise of two hours per week throughout the year. See above p. 89. 3 seniors and juniors, 7 graduates.

3. *Advanced Course in Experimental Psychology.* One lecture and one exercise per week throughout the year. Elements of analytical geometry and calculus with illustra-

tions from psychology; theory of probabilities; statistics; theory of measurements; practice in adjusting measurements; technical training in the construction and care of apparatus; principles of laboratory economy; methods of experimental instruction: practice in the use of the lantern, etc. 6 graduates.

4. *Educational Psychology*. One hour per week throughout a year. Application of modern psychological principles to educational subjects; outlines of the psychology of touch, its use in education; motor abilities, accuracy of movement, fundamental principles of writing and drawing; sight, color-teaching; space, form-teaching, drawing, modeling; attention, concentration and distraction, laws for developing attention; memory, analysis into its components, experimental study of, calculation of results, development and training, time of study; imagination, use, necessity of development and repression, fables, children's books, toys; emotions, will, action, reflex, automatic, instinctive, voluntary, their training; education of the blind, the deaf and other defectives; child-study, principles of anthropometry and psychometry; psychological development of the child, beginnings of instruction; economy in education, greatest results from least efforts, correlation and concentration of instruction; various educational subjects from a psychological standpoint,—amusement, play, toys, picture-books, object-lessons, etc. The course is illustrated with experiments, lantern views, and a large collection of educational material from Europe and America. 10 seniors and juniors, 2 graduates.

5. *Research-Work in Psychology*. Participants in this course are either investigators or assistants. For assistants the object is such a training in accurate introspection, observation, experimenting and the art of research as is desirable for the general psychologist. This work is open to all. Only those who have had sufficient experience are permitted to undertake independent investigations. The results of all investigations belong to the archives of the laboratory. Those who undertake investigations thereby agree to prepare the results for publication, subject to approval, in the *Studies from the Yale Psychological Laboratory*. 1 senior, 4 graduates.